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LOCAL CHAPTER OF AEE

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20-21 September 2023

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- Affordable Clean Energy
- Life on Land : Agriculture
- Economic Growth & Funding
- Industry Innovation & Infrastructure
- Sustainable Cities & Communities
- Responsible Consumption & Reduction
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14 March 2024

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Message from the President of the SAEEC

It is my pleasure to introduce Issue 3 of the Go2Energy Technical Journal. The SAEEC is proud of this publication that show cases technical and practical knowledge from industry professionals involved in the energy field in South Africa. I am continuously awed by the depth of knowledge shared in this journal series and the inherent commitment of the authors to their field and our industry at large.

Energy is life and in South Africa various aspects of life are being interrupted by the national energy crisis dubbed "loadshedding". This crisis has caused a spike in crime, hobbled the working from home revolution, slowed economic growth and pushed up food prices. Therefore, it is heartening to read articles that speak to the needs of the moment, the impact of energy efficiency, the benefit of renewable energy, the intersection of water security and energy availability, and the ever-apparent challenge of global warming.

As you read this third edition of the journal, I hope you are inspired to save energy through efficiency, to make yourself and your businesses more resilient through renewable energy and to conserve water in our daily lives. I would like to extend a note of gratitude to the authors for sharing their hard-earned knowledge with the energy family and look forward to more contributions in our next issue, Volume 4.

Best Regards,

Zadok Olinga
President of the Southern African Energy Efficiency Confederation

Welcome to The GO2Energy Technical Journal, Issue 3.

Dear Readers,

I am pleased to introduce issue 3, of the Go2Energy Technical Journal. As I read through the technical papers published in this issue, I paused and thought about the content that is being shared in this journal, and marveled at the depth of information that is available here.

I am passionate about furthering ones education and all three issues of the technical journal are testament of the specialized engineers we are so fortunate to have in our beautiful country. Engineering is an exact science and requires complex and in-depth mathematical knowledge and the ability to solve problems. It is a gift to those who pursue engineering as a career, and to those engineers who are keenly aware of the importance of the efficient use of energy and caring of the environment.

Thank you to the authors for permitting us to publish the papers you presented at our 2022 SAEEC Conference. This is so important as it spreads the all important message of saving energy.

Thank you to our technical editor, Mr. Martin de Lange for his support and input.

I wish you all an enjoyable read, and look forward now to publishing issue 4 of the Go2Energy Technical Journal.

Best regards in Energy Efficiency

Helen Couvaras

BA Honours (Byzantine Studies and Classical Culture)
Editor: Go2Energy Technical Journal.

Publisher

Southern African Energy Efficiency Confederation (SAEEC)
Reg no: 2016/443022/08
42 Webb Street,
Northmead,
Benoni,1501
Contact no: +27 84 011 5500
Info: secgen@saeeconfed.org.za

Guest Technical Editor: Mr. Martin de Lange
Sub-Editor: Helen Couvaras
DTP artist: Mr.Zoran Damjanovic, Crazy Cactus
Distribution management: Motlatjo Ramaloko

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Contents of TECHNICAL JOURNAL

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PERFORMANCE-COST BENEFIT ANALYSIS OF INSTALLING A ROOFTOP SOLAR PV/LEAD ACID AGM BATTERY IN A METAL CASTING COMPANY

T.Duma, B.Seteni, O.Dzobo

Council for Scientific and Industrial Researcha, Voltageonb, University of Johannesburg

ABSTRACT

In South Africa, Eskom as a public utility face many problems. It's 'biggest challenge' includes a poorly performing coal fleet affecting Eskom's Energy Availability Factor (the amount of energy generation a plant is capable of supplying to the grid). Their EAF was at 67.7%, below their target of 74% for the 2021 financial year. Such low performance is mainly caused by breakdowns that lead to load shedding; a phenomenon when the electricity demand exceeds the available supply. Such challenges drive business leaders to pursue alternatives to remain operational. Business leaders are now seeking solutions that can provide a secure, affordable, and environmentally sustainable energy supply system.

South Africa's industry & mining sector is energy intensive. Therefore, disturbances from load shedding are costly for such businesses ("time is money"). Continuous challenges faced by Eskom also results in annual escalation of electricity charges. The metal casting company is experiencing both challenges of load shedding and high electricity bills. This paper is investigating a viable energy supply solution for the metal casting company (company X for anonymity). The study used System Advisor Model (SAM) to conduct a techno-economic analysis of installing a rooftop solar PV with a lead acid AGM battery. If company X implements the proposed system, it can obtain energy cost savings of about R 1 227 210 per annum for the first year of commissioning.

Keywords: Solar PV, LiFePO4 battery, lead acid AGM battery, cost saving.

1. INTRODUCTION

Globally the energy sector is experiencing a revolution. This entails but not limited to policy implementation, cost reduction and installation of new solar photovoltaic (PV) electricity generation. The installation of solar PV is transforming the energy security, cost, and emissions (energy triangle). In 2021 globally solar PV generation reached a record of 179 TWh to exceed 1000 TWh. Regardless the solar PV installation and electricity generation expansion achieved in 2021, according to the International Energy Agency (IEA) greater efforts are still required to get on track with the 2030 milestones under the Net Zero Scenario. [1] [2]

South Africa's energy landscape is quickly changing due to national power grid decarbonization and supply-demand imbalances also known as 'load shedding'. Load shedding is a never-ending occurrence of scheduled blackouts. According to the Council for Scientific and Industrial Research (CSIR), South Africa experienced about 650 hours of load shedding (1 284 GWh) in the first six months of 2021. More so, they were significant since they were an upsurge compared to previous annual figures i.e., 127 hours (192 GWh) in 2018, 530 hours (1 352 GWh) in 2019, and 860 hours (1 798 GWh) in 2020. This means approximately 10 500 MW of the national utility is unavailable due to unscheduled breakdowns and 3500 MW is from scheduled maintenance. [3] [4] [5]

Further, Eskom's continuous annual escalation of the electricity tariffs is agonizingly felt by end-users. Notably, between year 1988 to 2007 electricity tariffs increased by approximately 223%, now between 2007 and 2022, the tariffs increased by approximately 700% while the inflation over the same period increased by 129% [6]. Eskom's revenue streams related to licensed activities are regulated by the National Energy Regulator of South Africa (NERSA). Eskom has recently applied to NERSA for a 32% electricity tariff increase; however, NERSA approved about 18.65% in January 2023. Continuous increase of electricity cost and frequent load shedding ("pay more, get less") is placing an enormous pressure on the balance sheet of many businesses. [7] [8]

Now company x's electricity bill is extremely high because of being energy intensive and continuous tariff increase from the utility. One of the solutions besides implementing energy efficiency, is installing a small scale solar PV rooftop plant. Solar PV system can reduce grid reliance and customer's electricity bill. However, the intermittent nature of solar limits it. Therefore, coupling solar PV with battery energy storage system (BESS) reduces the inefficiencies whilst creating a flexible system.

Table 1: BTM's battery dispatch modes

	Peak shaving dispatch mode using a battery	Manual Dispatch mode using a battery
Aim	Reduce peak power demand (kW) during 24-hours, resulting in reduced demand charges.	Dispatched for loads that are charged at time of use, especially peak and standard times.
Example of tariff charges	E.g., R102/kVA	E.g., Peak = R4/kWh, standard = R2.50/kWh off-peak = R1.05/kWh

The plummeting costs of solar PV and using BESS as demand response makes the system more investment attractive. Nowadays BESS can be used to reduce the electricity bill when used as Behind The Meter (BTM) dispatch modes i.e., peak shaving (kW) or during energy time of use (kWh). [9] [10]

This study used the BTM (Table 1) battery peak shaving dispatch model to shave off instantaneous peaks from the load to reduce or avoid demand peak penalties for company x. The battery inclusion ensures that the system is more robust. Appropriate sizing can reduce the battery cost i.e., O&M, LCOS. [11] [10]

2. SYSTEM DESIGN

2.1 Location and solar resource assessment

Company x is in a country called South Africa; city of Johannesburg as shown in Figure 1. The location of the foundry experiences about 5.49 sun hours a day and about 2149.8 kWh/m^2/year of direct normal irradiation, which makes the location suitable for installing a solar PV system.

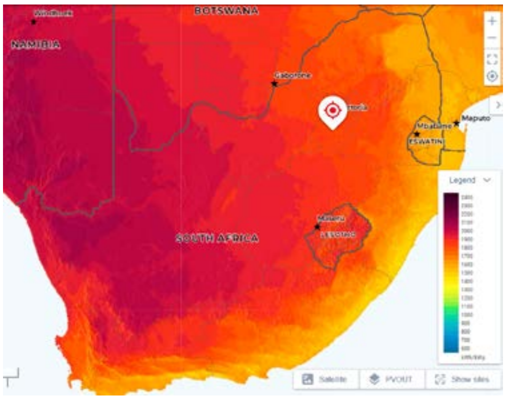

Figure 1: Solar resource data, courtesy from Global energy atlas, courtesy: https://globalsolaratlas.info/map

Estimations of solar PV outputs based on the solar irradiation in various locations in South Africa can range from 1400 kWh/kWp to 2400 kWh/kWp as shown in Figure 1 above.

Table 2: Solar resource data for company X

Global energy atlas data for the location of the company	
Country	South Africa
Province	Gauteng
Location (City)	Johannesburg
Latitude, DD	-26.212464°
Longitude, DD	28.04°
Specific photovoltaic power output	1798.5 kWh/kWp/year
Direct Nominal Irradiance (DNI)	2149.8 kWh/m²/year
Global Horizontal Irradiance (GHI)	2007.2 kWh/m²/year
Diffuse Horizontal Irradiance (DHI)	644.3 kWh/m²/year
Air Temperature	16.1°C
Altitude	1615 meters

According to global energy atlas about 1798.5kWh/kWp/year of solar PV power output is predicted for the foundry location. Solar resource assessment in Table 2 is an important step when designing a solar PV system because it detects whether the location is best suited for solar photovoltaic installation or other renewable energy sources. You can observe the number of sun-hours and average annual direct nominal irradiance (DNI), GHI and DHI to estimate how the system will likely perform under normal conditions. DNI is the amount of solar radiation received per unit area and its important when evaluating, optimizing your solar plant. [12]

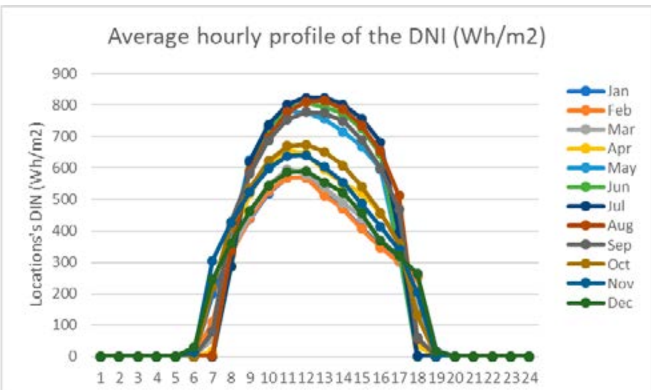

Figure 2: Hourly average direct normal irradiation data.

Figure 2 shows the monthly DNI for winter months is lower compared to summer or other seasons. However, this does not mean the plant will perform poorly during winter months. Its just that in winter the days are shorter causing less hours of sunlight [13].

2.2 Company X load profile assessment

The accuracy of designing and modelling a dependable solar PV system depends on the thorough understanding of the load profile. It is therefore important to understand the daily, monthly, and annual load profile to avoid oversizing or under sizing the solar PV system. Company X is a family business that was founded in 1991. It uses metal casting processes for manufacturing different components. Metal casting is simply a procedure of heating metal until it is liquefied and poured into an empty shaped space. The hot liquefied metal is then cooled, for an example using sand and when harden so it forms desired shapes for different applications. [14]

Company X occupies a site that is divided into two departments, sharing the sand storage and furnaces. The company has been on a journey of implementing green energy solutions. In 2019 it conducted energy efficiency audits that identified significant energy users to be induction furnaces (56%), compressors (22%), fans (7%), and pump motors (2%) as shown in Figure 3. These energy users consume about 90% of the site's total energy usage. The company recently retrofitted some of its inefficient lighting to efficient lighting, thus reducing total electricity usage. [14]

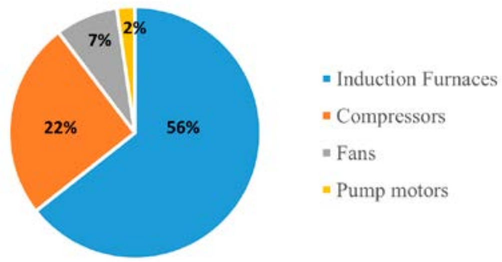

Figure 3: Identified significant energy users.

This study focused on the automotive department which will be referred as department A throughout this paper. Overall, the company consumes about 9,032,960 kWh ~ 9 GWh at a bill of about R 14,650,074 ~ R14 million per annum. The average monthly consumption of the entire site is about 752 747 kWh, with a monthly baseload of about 75 090 kWh. This data alone shows the energy intensiveness (tons/kWh) of company X. Thus, the need to implement energy-cost saving measures. [14]

Table 3: Profile for 'department A' of the company

Parameters	Values
Monthly energy consumption	65 171 kWh
Annual energy consumption	782 062 kWh
Average monthly peak demand	200 kVA
Annual energy cost (Bill)	R 1 746 855
Energy charges used in the model (2020/2021)	
Blended cost	1.18 R/kWh
Demand charge cost	79.31 R/kVA
Network access charge (NAC) cost	48.75 R/kVA

Table 3 shows the energy and cost data of department A of the company. The average monthly peak demand recorded was 200 kVA for year 2021 as shown in Table 3. The electricity charges for 2022/2023 have now increased

to about R60 /kVA (NAC), R103/kVA (demand charge), R7/kWh during peak, standard- R2/kWh, off-peak -R1.30/kWh (energy charges at time of use) at blended R3.43/kWh. There is also a fixed charge of about R2500/month if supplied at 400V. This proves that the company is still going to pay high electricity bills annually if it does not invest in implementing green energy solutions.

2.3 Technical design of the system

2.31 Single line diagram

Figure 4 shows the single line diagram of the solar PV/lead acid battery supply system for company X. The system is still grid tied, with most of the day being supplied by the solar PV system. The battery system is mostly used for peak shaving. Eliminating paying peak demand penalties from the municipality.

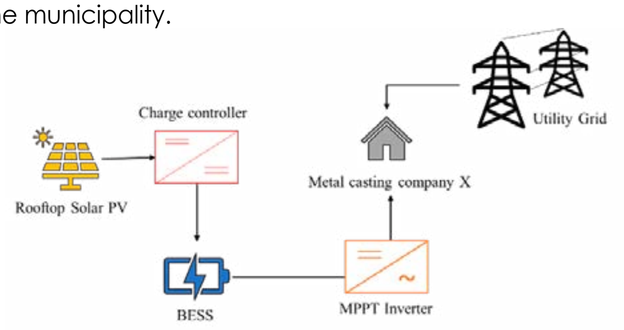

Figure 4: Single line diagram of the proposed system

2.32 Solar PV System sizing

The system is sized using the load profile of department A of the company. The first 547 kWdc rated capacity of the solar PV system is designed to meet the load (offset energy consumption) whilst ensuring energy-cost savings. The solar PV system's levelized cost of energy (LCOE) is cheaper than the utility grid therefore the foundry is expected to leverage on this low supply-charge.

Table 4: 547 kWdc solar PV rooftop plant

547 Solar PV system sizing design	
Rated DC Capacity	547.864 kWdc
Total AC Capacity	540.297 kWac
Inverter DC Capacity	550.325 kWdc
DC to AC ratio	1.01
Tracking	Fixed rooftop
Tilt angle (deg)	10
Azimuth angle (deg)	90
Ground coverage ratio GCR	0.3

The system in Table 4 does not produce excess power therefore it cannot be integrated with the lead acid battery, however this is to give the company options to choose the most viable system between the one with or without the battery energy storage. The system has a good DC to AC ratio of 1.01. Therefore, a second system is modelled to integrate the battery for peak shaving.

2.33 Component characteristics

This section shows the technical characteristics of each key component required to assemble a solar PV system. Each component was calculated based on the load requirement and load consumption profile of the company.

Mono-crystalline silicon module

A solar module or mostly referred as solar panels are made up from a series of solar cells. Table 5 shows the type of module used in this study with its characteristics.

Table 5: Module characteristics

Module Characteristics at reference position	
Ref condition	1000W/m^2, cell temp 25 degrees Celsius
Maximum Power	500.332 Wdc
Maximum voltage	42.8 Vdc
Maximum current	11.7 Adc
Open circuit voltage	51.7 Vdc
short circuit current	12.3 Adc
Nominal efficiency	21.38 %
Physical Characteristics	
Material	Mono-crystalline Silicone
Module length	2.34 m
Number of cells	75
Number of modules	1095
Total module area	2 562.3 m^2

The solar cells making up a module are sandwiched between a front glass plate and a rear polymer plastic backsheet supported within an aluminium frame. To date solar panels are increasing in efficiency performance, plummeting in cost, and increasing in demand within the energy space. [15]

Inverter characteristics

A photovoltaic inverter is also an important component of a solar PV system. It accepts output power from the solar PV panel and converts it from DC to AC [15]. This is when the loads to be supplied utilize alternating current (power) instead of direct current.

Table 6: Sizing the inverter.

Inverter characteristics	
Max. AC Power	60033 Wac
Max. DC Power	61147.2 Wdc
Power use during operation	148.792 Wdc
Power use at night	0.9 Wac
Nominal AC voltage	480 Vac
Max. DC voltage	800 Vdc
Max. DC current	84.92 Adc
Nominal DC voltage	720 Vdc
No. of MPPT Inputs	1
Weighted Efficiency	98.22%
Number of Inverters	9
DC/AC ratio	1.01

Mathematical calculations to accurately size the inverter were used to eliminate over/under sizing the inverter. Inverters must supply constant frequency and voltage despite varying load conditions. Table 6 shows the characteristics of the inverter used in this study. About 9 inverters are required to convert and supply the load with AC power.

Lead acid (AGM) battery characteristics

Lead acid batteries are used in different small to large applications. They are also used in solar photovoltaic applications. These batteries have moderate efficiency, low

energy density but costly to maintain, especially for large applications [16]

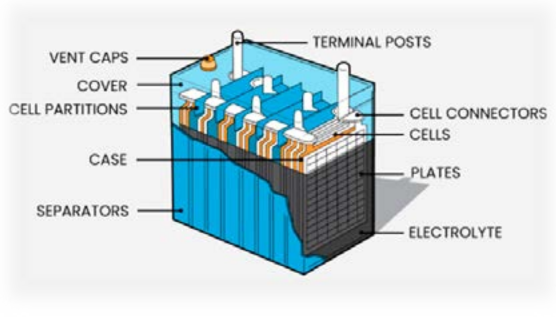

Figure 5: Lead acid AGM battery [17]

Lead acid batteries as shown in Figure 5 store electrical energy by means of chemical reactions between water, lead, and sulfuric acid [18]. A lead acid battery can supply high surge currents resulting in large power to weight ratio (measure of actual performance) [19]. Generally, lead acid batteries are usually used in vehicles, back-up power in cell phone towers and in stand-alone energy storage systems [19].

Table 7: Pros and cons of the lead acid battery

Advantages of lead acid battery	Disadvantages of lead acid battery
Commonly used for rechargeable applications.	Average charging efficiency at about 70%.
Well established in the market.	Electrolyte is corrosive.
Robust and reliable.	Expensive for BESS installation.
Cheaper to purchase for small applications.	Not environmentally friendly.
Applicable in a variety of applications.	Not appropriate for fast charging.
Able to tolerate overcharging.	Acid requires disposing with care

Table 7 shows some of the advantages and disadvantages of the lead acid battery [16]. This is important specially to understand the limitations of the battery system during the design phase.

Table 8: Lead acid AGM used

Physical Properties	
Battery mass	33 000 kg
Battery surface area	86.6 m^3
Specific energy per mass	35 Wh/kg
Energy capacity of one module	400 kWh
Thermal properties	
Single environment temperature	25°C
Specific heat Cp	660 J/kgK
Heat transfer coefficient h	7.5 W/m^{2}K
Lead Acid AGM battery sizing	
Desired bank power	288 kW
Desired bank capacity	1152 kWh
Desired bank voltage	500 Vdc
Cell nominal voltage	2 Vdc
Cell capacity	30 Ah
Lifespan	500 cycles at 50% DOD
Days of autonomy	1 day

In Table 8 the physical, thermal and battery sizing characteristics of the lead acid AGM battery are tabulated. Battery sizing is crucial when integrating with solar PV system because over sizing increases the cost of purchase and maintenance of the battery system. The study pays attention in reducing the cost of the battery by reducing the capacity and days of autonomy, since the battery is mainly for peak demand shaving. The desired battery bank power in Table 8 is based on the average monthly peak demand of the load. The battery is connected to the DC side of the solar PV inverter. This means that the battery will stop charging or discharging when the inverter efficiency is less than inverter cut-off efficiency.

2.4 Mathematical model

Solar PV capacity sizing

Is done to offset the energy consumed by the load. They are different kinds of equations that are used to size the PV array, but this study used Eq.(1).

$$\text{Size of the PV array (KW)} = \frac{\text{average monthly load in kWh}}{[\text{Sun} - \text{hours per month}] * [\text{Derate factor of } 0{,}77]} \tag{1}$$

Where,
Monthly load (kWh) is the energy consumed by the company.
Number of sun-hours per day is obtained from the location.
Derate factor is used to reflect the electrical losses from the system's DC/AC conversion.

Net Present Value (NPV)

Is used in investment planning to evaluate the profitability of a project [20]. When a NPV is negative it implies that the project has a high risk of not being profitable but an energy saving project with a positive NPV is considered for investments. It can be calculated using Eq. (2)

$$\text{NPV} = \frac{\text{Rt}}{(1+\text{r})\text{\^{}t}} \tag{2}$$

Where,
'Rt' is the net cash flow at time t, 'r' is discount rate, and 't' is time of the cash flow.

Battery sizing

Battery coupling with Solar PV can consider different factors such as the application of the battery, battery chemistry used, the days of autonomy and the Depth of Discharge (DoD). This study used Eq.(3) to size the battery for peak demand shaving.

$$\text{Battery size (kWh)} = \frac{\text{DL (kWh)}*\text{DOA}}{\text{DoD}} \tag{3}$$

Where,
You need the daily load profile (kWh), DoD = Depth of discharge (set to preserve battery durability), Days of autonomy (number of days your battery must be self-sufficient, higher number of days, means large battery size is required and this results in high cost).

Levelized cost of storage (LCOS)

Is the cost of electricity that is discharged from a storage technology, accounting for all cost and energy generated throughout the lifetime of the technology [21]:

$$\text{LCOS} = \frac{\text{Capital} + \sum \frac{(\text{O\&Mt}(1+\text{i})^{\text{t}} + \text{Fuelt}(1+\text{e})^{\text{t}})}{(1+\text{r})^{\text{t}}}}{\sum \frac{(\text{MWht}(1+\text{e})^{\text{t}})}{(1+\text{r})^{\text{t}}}} \tag{4}$$

Where,
One considers the capital which is the net cost of the battery energy storage system, O&Mt is the operations and maintenance costs over time t, fuelt is the cost of electricity stored over time t, MWht is the electricity delivered by the BESS over time t, 'r' is the discount rate (%), 'i' is the inflation rate (%), and 'e' is the annual coefficient of correction of the cost of electricity (%). [22]

Inverter sizing

Is important because the inverter converts DC power to AC thus correct sizing reduces losses. Also, its power rating should be greater than the total peak power of the load. When sizing an inverter, a margin factor of at least 10% should be considered, for a good installation durability. [15]

$$\text{Inverter size (kW)} = \frac{\text{Lp} * \text{ Mf}}{\text{PFi}} \tag{5}$$

Where,
'Lp' is the peak power of the load, 'Mf' is the margin factor and 'PFi' is the inverter power factor.

Module sizing

Is a critical component when designing and modelling a solar PV system because the number of solar modules should determine the rated output power of the solar PV system. Panel sizing can be calculated using Eq. (6).

$$\text{No of modules} = \frac{\text{Solar PV system rated capacity}}{\text{Rated power of each module}} \tag{6}$$

Where,
Solar PV rated capacity is determined according to the load and availability of space, Module rated capacity is the rated power of the module according to the manufacturer.

DC to AC Ratio

Is a ratio that considers the installed DC capacity of the solar PV system to the inverter's AC power output. Ideally a DC/AC ratio should be greater than one. This ensures that system power loss is reduced during the conversion (output is relatively close to the input). [15]

$$\text{DC to AC ratio} = \frac{\text{Module DC capacity}}{\text{Inverter AC capacity}} \tag{7}$$

Module self-shading

Is important to consider during the design and modelling stage because the output of a solar PV system can be affected by module shading. They are different types of module shading whether from self or external shading e.g., trees, soil, snow etc. Eq. (8) was used to determine row spacing to eliminate module self-shading. [15]

$$\text{Module row spacing (Y)} = \text{X} * \frac{\cos(\text{azimuth angle})}{\tan\text{ (altitude angle)}} \tag{8}$$

Where,
'X' is given by Sin (Tilt °) multiplied by the length of the array in meters, Azimuth angle is the compass direction from which the sunlight is coming from, which varies according to time of year and latitude, Altitude or elevation angle considers how high the sun appears in the sky. [15]

String sizing

Is the calculation made to determine how many solar panels must be connected into one inverter input for optimum efficiency. [23]

$$\text{Max. modules per string} = \frac{\text{Inverter maximum voltage}}{\text{Module rated Voc}} \tag{9}$$

or

$$\text{Min. modules per string} = \frac{\text{Inverter minimum voltage}}{\text{Module rated Voc}} \tag{10}$$

Where,
'Voc' is the module open circuit voltage, and we consider the inverter's maximum and minimum rated voltage.

A panel string is a group of panels wired into a single input of the inverter as shown in Figure 6.

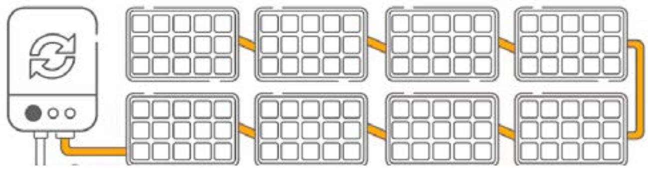

Figure 6: A panel string-inverter connection. [23]

Cost inputs

Table 10 shows additional cost inputs used in the modelling of the solar PV/lead acid AGM battery. The estimated values were based on the year 2020/2021 when this study was initiated. The lead acid AGM battery increased the cost of the overall system because of high installation and maintenance costs.

Table 10: Cost model

Category	Description	Value	Units
Financial	Inflation rate	6	%
Financial	Nominal discount rate	10.03	%
Financial	Electricity bill escalation rate	13	%
Financial	Debt percentage (if the company invests)	0	%
Incentives	Government incentives	0	R
Tariff Charges	Demand charge savings Fixed charge	79 48	R
Tariff Charges	Peak Standard Off-peak	4.79 2.00 1.15	R

3. SYSTEM METHODS

3.1 Methodology

The modelling of the study was done using System Advisor Model, cost calculations, component selection inputs and sizing calculations for the solar PV and battery system.
The model makes use of key input variables as shown in Figure 7. The inputs include but are not limited to average daily/monthly load profile, solar irradiance, module size, inverter size, battery criteria, battery dispatch mode, electricity tariffs, annual tariff increase rate, interest rates, and inflation rates.

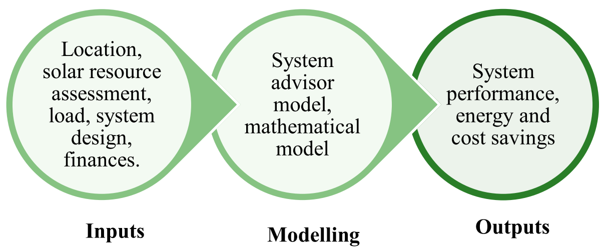

Figure 7: Methodology for the solar PV/lead acid system.

This model is designed to have a solar PV system paired with a lead acid battery for cost saving benefits. The battery is intended to be used as a behind the meter dispatch model. The model is set to use peak-shaving (look-ahead). Peak demand shaving refers to the flattening out of peak use of electricity to eliminate peak demand charges. The model restricts the lead acid AGM battery to follow this concept:

- charge the on-site battery storage system at lowest cost using solar PV system. Although the grid is less expensive during the night, avoid charging because solar PV is still the cheapest option.
- discharge the lead acid AGM battery during peak demand to eliminate paying peak demand penalties from the municipality.

The system performs on the functionality of time. According to the illustration flow in Figure 8, the system measures the amount of solar PV output power: whether it is enough to supply the load and to charge the battery bank. The flow of the system is designed to ensure that the load is supplied continuously without any disturbances.

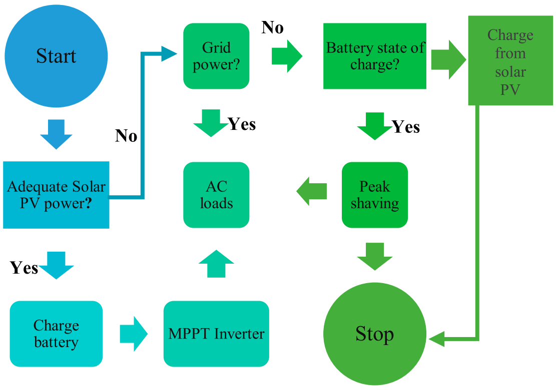

Figure 8: Flow chart of the grid tied solar PV/lead acid battery system.

The solar PV system is a cheaper option and is designed to supply the load during the day when electricity is charged at peak and standard times and during load shedding events. The lead acid battery is meant to supply the load during peak demand.

Peak demand penalties contribute to the high electricity bill of company X. Thus, methods to reduce peak demand charges are always beneficial. The battery energy storage system creates flexibility when coupled with a solar PV system because it not only stores access energy for night load but also for demand response opportunities for even industrial customers.

The system uses a charge controller to regulate how much solar power is best to charge the battery bank. The system also uses a Maximum Power Point Tracking (MPPT) inverter to convert DC power to AC power. The MPPT featured on the inverter is a better option because it assures maximum efficiency of the solar PV panels at any conditions. [15]

4. RESULTS AND DISCUSIONS

This section focuses on discussing the results obtained from modelling the systems. The overall objective was to study the impact of using lead acid battery for peak demand shaving when coupled with a solar PV plant. As mentioned before, the smaller solar PV plant is designed to offset the energy consumed by the load. However, the bigger plant yields excess energy making it possible to add a lead acid battery.

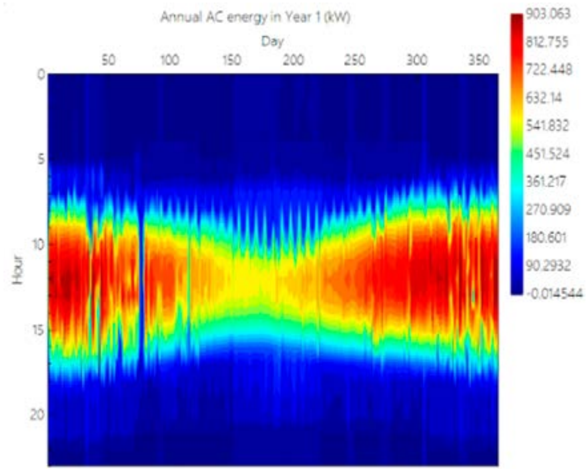

Figure 9: Heat map showing the energy production of the location of company X.

The heat map in Figure 9 shows the predicted energy generated throughout the year for the company location. The hourly solar production of the system could reach about 900 kW during summer peak hours and about 200 kW on most days during winter months (Figure 9). As a result, a battery energy storage system is still required to be paired with solar PV for system flexibility. The optimal energy production is higher during the day between 8h00 am to 16h00 pm.

Table 10: Technical and cost results of the model

Parameters	A 547 kWdc solar PV system	A 990 kWdc solar PV/lead acid battery system
Energy yield	1712 kWh/kW	1694 kWh/kW
Annual energy generated	937 847 kWh	1 677 773 kWh
Performance ratio	0.83	0.83
Levelized COE	77.76 c/kWh	180 c/kWh
Battery cost per usable kWh per cycle	n/a	R 48/kWh
Battery roundtrip efficiency	n/a	89.11%
Current electricity bill	R1 746 855	R1 746 855
Electricity bill with the new supply system	R 941 960	R 519 645
Cost savings (year 1)	R 804 894	R 1 227 210
Cost savings (percentage)	46%	70%
Net present value	R42 584 774	R35 122 420
Investment cost	R7 264 671	R 19 314 314
Discounted Payback period	6.3 years	17.4 years

547 kWp solar PV rooftop plant

The first plant with a capacity of 547 kWp with a 'year 1 SAM' electricity production of about 937 847 kWh as shown in Table 10. This is based on weather data for the location of company X. The model predicted an 83% performance ratio. The possibility of the plant under performing is based on different variables such as losses, shading or cable theft. The plant can offset the energy used by the load and save company X about 46% in energy cost.

Additional implementation of the energy efficiency measures for the compressors and lighting load will further add about 10% cost savings. The investment of installing the plant is about R7 million with a payback period of about 6 years. If the company is not able to add the battery energy storage system using a bigger solar PV system to increase energy-cost benefits, they can opt for the 547kWp system. This is because this system can meet the requirements of the load.

990kWp Solar PV paired with lead acid battery.

The second solar PV system with a capacity of 990kWp is paired with a lead acid battery for peak demand shaving. The goal in increasing the capacity from 547kWp to 990kWp was to have enough surplus energy for storage and dispatching. The 990 kWp plant has a 'year 1 SAM' electricity generation of about 1 678 756 kWh. The system does yield the cost savings; however, the cost of investment is high because of the battery addition. The integration of the lead acid AGM battery has advantages such as long life, high cycles and can be discharged at 80% capacity although 50% is preferred for prolonging battery life. Such advantages are costly though as the AGM battery can cost 2 times per kilowatt-hour (kWh) of energy stored. Other shortcoming costs associated with it include installation cost, transportation cost and maintenance cost. Inclusion of the small-scale battery storage with solar PV is still encouraged as the LCOS keeps dropping.

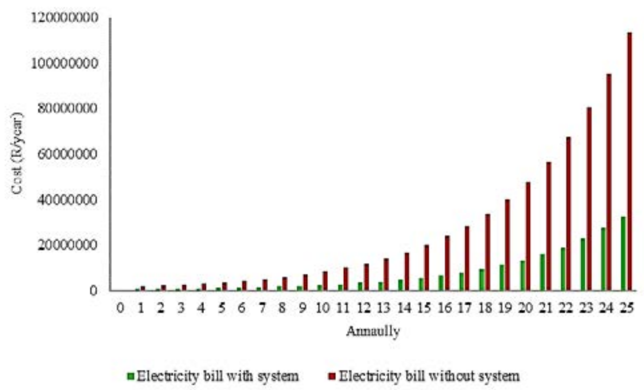

Figure 10: Electricity bill scenario for a 25-year period

Overall both systems yield energy cost savings, however the intermittent nature of solar is still alarming. However, the battery energy storage system creates an energy mix not only for back up power, but also for a more resilient system. Figure 10 shows a real forecasted scenario of what could happen when the company does not implement 'green solutions'. The bar graph in Figure 10 is showing a scary insight of how much the company will be paying when supplied by the utility alone. Now small-scale embedded generation for energy intensive industry sub-sector as company X cannot escape the challenges faced within the electricity market in South Africa. Therefore in order to stay operationally sustainable the company must be willing to "spend money to make money" whilst implementing a viable business case with high energy-cost savings, positive net present value and a lower payback period. To date history and literature has shown that solar PV systems are the optimal solution in combating the struggles of high electricity charges. More so, battery energy storage can solve the crisis caused by load shedding.

5. CONCLUSION

Eskom has proposed a 3-year term of permanent stage 2&3 of load shedding. It is also continuously increasing electricity charges annually. This is affecting the economy of the country greatly as more businesses fail to keep up with these encounters. The future of the energy sector is certainly a mix of energy generating sources with a least-cost option being prevalent. Solar PV system provides a more predictable energy output, thus ensuring energy-cost savings as shown in Table 10. Hence, integrating solar PV with a battery energy storage system increases the energy-cost benefits as shown in this study.The pairing of solar PV with BESS for small-scale prosumers should be examined accordingly i.e., battery type, battery system requirements, sizing, days of autonomy, costs, and technical performance. This enables the use of a cost-competitive battery type. The lead acid AGM battery is not cost-competitive (especially for large scale applications) when compared to other matured batteries in the market i.e., lithium-ion battery.

6. ACKNOWLEDGMENT

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Principal Author:

Ms Talent Duma holds a bachelor's degree in Electrical Engineering (Power systems) from Tshwane University of Technology. She is currently pursuing a MPhil: Electrical and electronic engineering science from the University of Johannesburg. She is currently working as a research technologist at the Council for Scientific and Industrial Research (CSIR) focusing on demand side management, energy supply and battery energy storage modelling for least cost and sustainable solutions.

Co-author:

Dr Bonani Seteni has a Ph.D. in Energy Storage Materials from the University of Johannesburg. He holds several patents in lithium-ion battery development. He specializes in energy research (system performance and financial modelling), project management, and the latest thinking and best practice in energy leadership. He is currently a senior researcher at Voltageon focusing on energy planning and economic supply chain impacts of expanding electricity access in South Africa.

Co-author:

Dr Oliver Dzobo is a senior lecturer at University of Johannesburg, South Africa. His research interests are in power system optimization, energy storage and application of blockchain technology in energy delivery.

Presenter: The paper was presented by Talent Duma.

DELINEATING THE SCOPE OF HYDRO STORAGE IN THE ARRAY OF ENERGY STORAGE TECHNOLOGIES

Thea Naudé, EHL Engineering, Centurion
Theunis Steyn, KMLS, Nelspruit

1 ABSTRACT

The expectations of the Electricity Supply Industry are typified by power shortages on the national grid and international obligations to reduce its carbon footprint.

Subsequently, a general understanding for the medium term is to establish 50 000 MW of renewable energy installation with 10 000 MW energy storage capacity (with a 4-hour cycle).

Whilst the technology and implementation methodologies for wind and solar are well established, there are several factors affecting energy storage namely a differing range of technologies with rapid improvement in performance levels.

Measured against the deployment levels of renewable installations, it will necessitate a focus on the expected energy storage capacity. For this, the prevalent opinion is that chemical batteries are the outright preferred solution primarily due to the low energy density, high capital outlay and long lead times of Pumped Hydro Energy Storage (PHES).

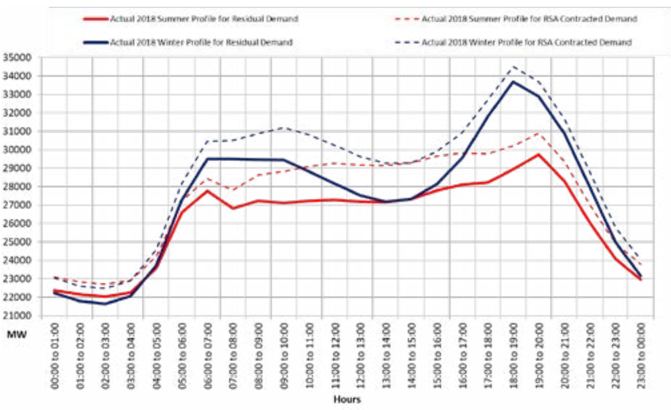
In such an analysis, the other aspects which must be considered are the longer operational life of hydro systems and application of innovation to create more flexible hydro energy storage systems.

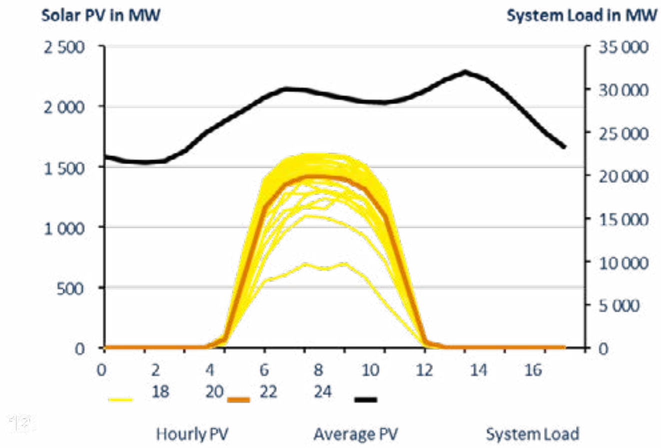
Recently a 4-month-old Tesla Battery storage facility caught fire, this was only 1 of 40 large Lithium-Ion battery fires in operation or whilst being shipped, leaving some serious questions for BESS.

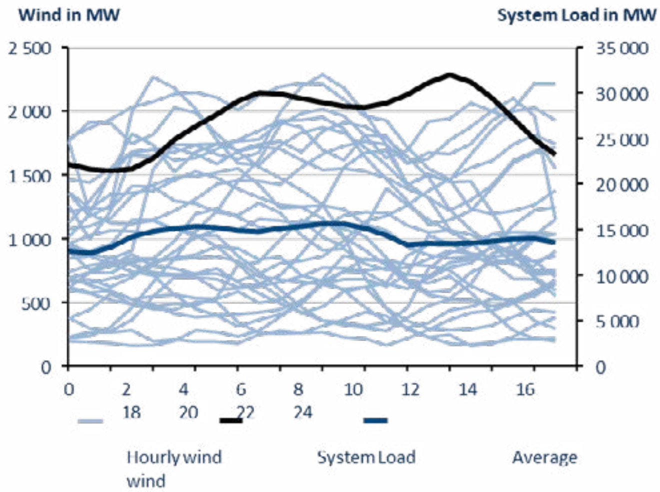
2. ELECTRICITY SUPPLY INDUSTRY: MEDIUM TERM PROSPECTS

A school of thought within the South African economy [1], to address the shortfall caused by the failings in the coal fired power stations, is that an additional 50 GW of solar and wind must be added to the grid but energy storage with a capacity of 10 GW will be required to avert large scale loadshedding.

On this basis, the following analysis revisits the perceptions surrounding PHES.







Summer wind generation (8 months) aligns perfectly to our load profile, and we are blessed with high wind output. However, in winter it is much more random and is driven by cold fronts. It gives us twice the challenge because the wind increases as the cold fronts traverse Western and Eastern Cape.

As the cold front passes, the wind drops dramatically, and this coincides with the cold weather reaching Gauteng where most of the country's load is. This means that not only do we have to deal with the drop in wind generation but also the increase of load by dispatching conventional plant.

3. REVIEW OF ENERGY STORAGE TECHNOLOGIES

As markets and policymakers introduce greater renewable capacity to achieve climate change goals, forcing out conventional generators, some electricity will be free, except when it's really needed. Energy storage on a large scale is needed for sustainable business in South Africa.

Whilst PHES is an established technology, there are an array of alternatives under development / investigation. For reference purposes, a typical outline is captured in Annexure A [2].

The selection of an energy storage system depends on the specific requirements like location, size, reaction time and funding but in general, capacity, efficiency, life cycle cost per MW, scalability, easy access, availability of mature technology, off-the market components, environment friendliness, and many other factors are desirable to various degrees.

The dynamics of this market renders predictions an untimely exercise. The overall observation is that:

- Innovation is a definitive feature
- Due to the capital requirements the average storage capacity is around 100 MW, and
- The market is responding to an availability period of 4 hours per cycle

The situation pertaining to PHES is that its prominence has been lost in the current market conditions whereas chemical batteries are the leading development option. The subsequent investigation will focus on a comparison of these two technologies.

4. RELEVANCE OF PUMPED HYDRO-ELECTRIC ENERGY STORAGE (PHES)

Estimated on the overall power capacity, storing water at a gravitational surplus is the only method that achieves on an ultra-large scale. It is this very trademark which renders it unattainable to the typical financial institutions due the required level of capital intensity.

This situation can be illustrated (per Table 1) by an evaluation on present industry initiatives.

Table 1: Key Indicators on Energy Storage

Indicator	Eskom BESS Phase 1	Eskom BESS Phase 2	Eskom BESS Total
Battery [MWh]	833	616	1449
Cost ['m]	$320	$400	-
Cost ['m]	R5 280	R6 600	R11 880
R/kWh	R6 339	R10 714	R8 199
Indicator	Ingula (2016)	Ingula (2022)	Drakensberg (Refurbished)
Battery [MWh]	21 000	21 000	27 600
Cost ['m]	$3 500	$3 942	$1 036
Cost ['m]	R25 000	R65 036	R17 095
R/kWh	R1 190	R3 097	R619

The parameters for the Battery Energy Storage System (BESS) [3] are part of a program presently being undertaken by Eskom with an indicative rate of ± R8 200/ kWh. Eskom will be constructing its first solar and battery storage projects at Komati, Majuba, Lethabo and several other power stations. This will result in over 500 MW being added to the system. This should be compared to Eskom's latest PHES at Ingula which remains competitive even with an updated cost comparison. This aspect becomes even more pronounced when it is acknowledged that, due to the capital cost for Drakensberg PS being amortised, that a fully refurbishment of that plant will render a storage rate of less than 10% compared to BESS. These values demonstrate the importance of patient capital in the creation of social assets.

Including an estimate of the historical value of the Drakensberg scheme does pronounce these indicators in stark terms. Per the cost of this PHES was around R170 million in 1982 [4]. At an average inflation of 8.1% per year over the last 40 years, this capital in present terms should be R4.1 billion which equates to storage rate of R148/kWh. Some pertinent observations in this regard are that there was a significant increase within the cost structure of the electricity industry (far above inflation) over the past few decades and most importantly, these figures demonstrate the value of patient capital in the creation of social assets.

Such an examination becomes more intricate once the full logistical chain in the formation of such installations is accounted for. Per estimates of Voith (2018) [5], there is a case to be made that a life cycle estimation of material / resource cost for BESS is at least an order of magnitude higher than that of a PHES system. It is due to these attributes that the latter option deserves due attention [1].
Some of the most important benefits of PHES are:

- **Can run extended hours****
  Drakensberg unit hours 1 000 MW = 102 hours, 4 units = 25.5 hours
  Ingula unit hours 1 330 MW = 58 hours, 4 units = 14.5 hours
  Palmiet unit hours 400 MW = 60 hours, 2 units = 30 hours
- **Fast Dispatch/ Power System Flexibility**
  Pumped Storage → 200 MW/min load-up
  Coal → 8MW/min load-up
  OCGT's → 12 MW/min load-up
  270 MW/min Ingula → extremely fast dispatch
- **Adds fault level**
  synchrony generators (inertia)
- **Assist with Voltage control**
  even in Sync-condensing mode

** *actual operating MWh varies slightly from initial design capacity*

5. FORECAST FOR PHES

A most contemporary storage system that deserves mentioning is the Switzerland, Nant de Drance Power plant, Swiss canton of Valais. [6]

Table 2: Basic parameters
The basic installation parameters are as follows:

Storage Capacity [kWh]	20 000 000
Capital (CHF)	2 000 000 000
Dollar: CHF	1.05
Capital (USA)	$ 2 100 000 000
Rate [$/kWh]	$ 105.00
Exchange (R/$)	R 16.50
Rate [R/kWh]	R 1 733

Measured against the yardstick of capital per unit energy, in this case the rates of Eskom's BESS pale in comparison to PHES rates.

An examination of this validates the storage program being undertaken in China. In 2010 their forecast for this industry was to grow from a base of 17 GW up to 50 GW by 2020. [7]

Although this was quite an ambitious target, they seem to have attained 40 GW by 2020 with another potential of 60 GW to be gained. [8]

Assessing the national status of electricity generation, it is evident that:

- The status and performance of the coal fired power stations will render load shedding a re-occurring phenomena.
- Due to an immediate generation shortage along with environmental pressures the addition of variable renewable energy sources, i.e., solar / wind, to the grid will be inevitable.
- By nature, these sources are intermittent and the success of its integration with the market will depend on dispatchable energy storage systems.

It is in these circumstances that PHES can offer definitive outcomes.

6. FEATURES OF CONVENTIONAL PHES

It is the characteristics of large-scale hydro systems which governs the perceptions of its applicability as an energy storage alternative.

The customary arrangement of the hydro-energy repository is the linkage of an upper reservoir to one below by means of a penstock which is a large, enclosed channel. Due to the required flow rate, these conduits are of sizeable diameter and once a substantial hydraulic head comes into the equation, the preferred manner of construction is to tunnel through the mountain. Although this type of civil work is expensive, it is still more economical than an equivalent penstock manufactured of steel.

Single turbines

The result is that this type of technology has gained a status of being hampered by long lead times with significant capital intensity. However, given the expected market demand for energy storage, the suitability of PHES should be revisited.

Table 3: Cost of Alternative Penstock Materialization

Relative Cost: Penstock Alternatives per Diameter (m)		
Diameter	**Tunnel**	**Steel Pipe**
1.0	R47 123 890	R106 977 278
2.0	R188 495 599	R426 536 864
5.0	R1 178 097 245	R2 663 854 206
10.0	R4 712 388 980	R10 654 845 054
15.0	R10 602 875 206	R23 973 401 371

For illustration purposes, benchmarking for a hypothetical installation, at a hydraulic head of 900 meters over a length of 6 000 meters is listed in Table 3. At an excavation rate of R10 000 per cubic meter against a steel price of R35-00 per kg, the penstock's cost comparison points towards a value of more than two times for a steel pipe in relation to an underground tunnel. This is mainly due to the increase of the pipe's wall thickness along with the progression in the water head.

7. PROSPECTS OF PHES IMPLEMENTATION

An appropriate metric in the comparison of technology types is by means of technology curves, as captured in Annexure C. The notable observation is that PHES, based on the size of installed capacity and relative cost, is a mature technology.

Even as Li-ion batteries claim a comparative cost rate to PHES, the aspects to be kept in mind are that:

- this breakeven point is to come about in 2025 (**Figure 1**) although:
- the latest market prices captured in **Table 1** still list a considerable premium for BESS in the SA market but
- the expectation for PHES is to be constantly priced whilst there must be credit given for innovation.

The future cost of electrical energy storage based on experience rates. [9]

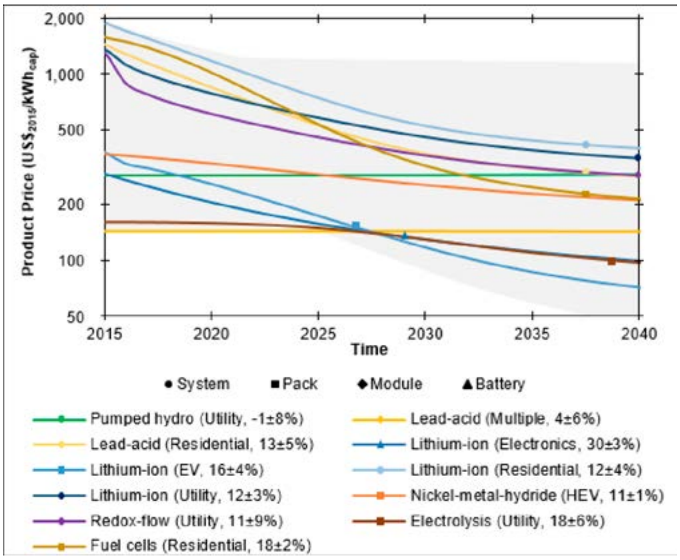


Figure 1: Cost Forecast – Energy Storage

Therefore, as typified in scientific enquiry, the liberty of alternative opinions should be catered for. [10] With this outlook, Figure 2 captures values that list PHES as a most competitive option, especially when taking a levelized cost approach.

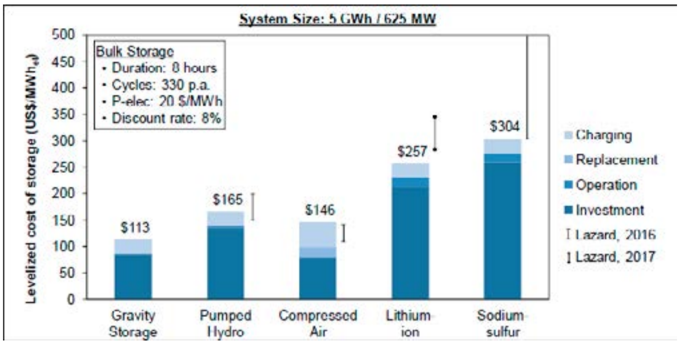


Figure 2: Relative Cost – Energy Storage Technologies

Given this background a peculiarity in the SA industry is one of the reasons why Eskom's PHES at Steenkampsberg fell by the wayside. Debating from the basis that its benchmarking parameters should be in the same order as that of Ingula, the value of R3 000 / kWh is still less than half of the BESS project. Measured against the features of PHES, this prospect should be revisited as a matter of national priority.

8. PHES INNOVATION OPPORTUNITIES

Considering the medium-term power supply shortage expected on the Eskom grid along with the relative cost of BESS, market should respond well to PHES schemes that can be established with curtailed lead times and at a scale that delivers higher capacities than the latest battery storage solution.

It is at this juncture that innovation becomes a factor. By surveying the overarching environment, it can be claimed that:

- Between the extensive mountain ranges and numerous deep level mine shafts, there is a material chance of wide scale deployment of mega-scale PHES systems
- Defining a generating capacity level that reduces the capital outlay can secure interest of private investors and
- a reduced cost of the penstock is attainable by re-configuring it to a piped channel along with the serial placement of turbines, illustrated in Figure 3, along the penstock

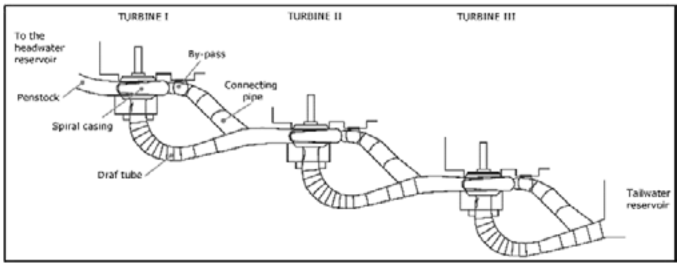


Figure 3: Configuration – Serially Positioned Turbines [11]

Table 4: Parameters – Conceptual PHES

Static Head [m]	800
Total Length [km]	6.0
Hydro Generation Sections (#)	8
Unit length per hydro section [m]	750
Generation Mode per Cycle (h)	8

It might be a stroke of destiny but the incremental capacities distribution equipment to cater for the typical customer requirements. With this outlook, a representative PHES capacity of 90 MQ that will require a waterflow of ± 11 m³/s through a penstock with a diameter of ± 2,0 m is investigated to compare to the cost of potential alternatives. This will then require a waterflow of ± 11 m³/s through a penstock with a diameter of ± 2.0 m.

Table 5: Hydro Capital Estimate (Single Turbine)

Element	U.oM.	Qty	Total ZAR	Ratio
Penstock	[m]	6 000	R439 989 418	33%
Turbine	[MW]	86	R147 660 000	11%
Generator	[MVA]	85	R195 500 000	15%
Substation	[MVA]	85	R204 000 000	15%
Reservoir – Top	[m³]	78 612	R8 214 980	1%
Reservoir - Bottom	[m³]	94 335	R9 857 976	1%
		Contingency	**R331 723 383**	**25%**
		System Total	**R1 336 945 757**	**100%**

The costing of the alternatives is then for a conventional setup (captured in Table 6) versus a system with a turbine at each of the four sections.

Table 6: Hydro Capital Estimate (Per Hydro sections)

Element	UoM.	Qty	Total	Ratio
Penstock	[m]	1 500	R32 804 771	13%
Turbine	[MW]	21.4	R36 915 000	15%
Generator	[MVA]	21	R48 300 000	19%
Substation	[MVA]	21	R50 400 00	20%
Reservoir – Top	[m³]	78 612	R8 214 980	3%
Reservoir - Bottom	[m³]	94 335	R9 857 976	4%
		Contingency	**R61 542 600**	**25%**
		System Total	**R248 035 326**	**100%**
		System Total	**R992 141 304**	

These estimates are not firm market rates but are applied to demonstrate the potential saving by dispersing the turbines along the penstock. Thus, the alternative listed in Table 6 does hint at a potential saving of 25% against the conventional methodology.

9. FEASIBILITY – PHES

The typical economic demands on a PHES scheme is that it operates in the generation mode during peak cycles. This implies that to make such an installation viable the selling tariff should exceed the sum of the capital rate plus the energy charging cost.

Based on the benchmarking figures, the alternative system could be established at a potential rate of ± 100 c/kWh with solar energy being in the same order. If this is valued against the weighted average peak tariff of ± 200 c/kWh for Megaflex, there must be justification to pursue this solution.

10. POTENTIAL PHES PROGRAM

Due to the economic history of SA, there are extensive industries present around the redundant mine shafts of Gauteng. Similarly, new mining developments in Limpopo are in the vicinity of mountain ranges. Recognizing these factors, the development of PHES systems to address defi-

ciencies in the ESI is a challenge laid before the engineering fraternity.

11. OPPORTUNITIES FOR UNDERGROUND PUMPED HYDRO-ELECTRIC ENERGY STORAGE (UPHES) [12]

When existing infrastructure is used to facilitate the generation of electricity the economy of UPHES will become even more evident.

Hydro Battery showing typical pump infrastructure for Shafts.

Summary of calculations of what could be achieved with current infrastructure if used as UPHES.

Table 7:

Pumping Power [MW]	12.5
Pump Time [hr]	6.5
Pump Energy (MWh]	81.16
Turbines Power [MW]	10.4
Turbine time [hr]	5 000
Turbine Energy [MWh]	51.94
Volume [Ml]	7.49
Typical Haulage Length [m]	832
Pump / Turb Power	120%
Roundtrip Efficiency	64%

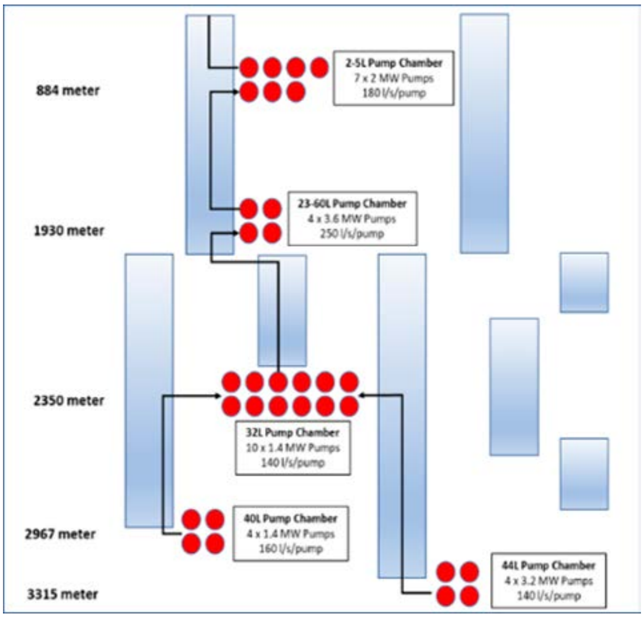


Figure 4: Hydro Battery that shows typical pump infrastructure for Shafts

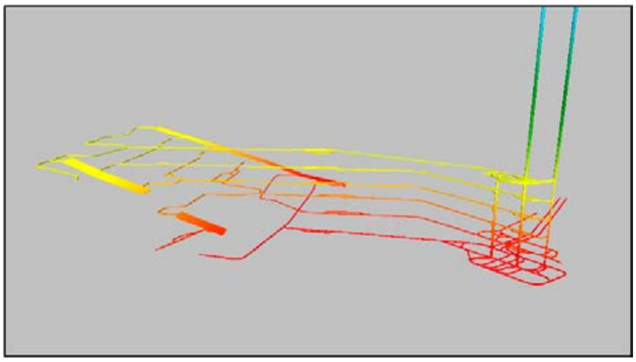


Figure 5: Example of underground haulage (1) [12]

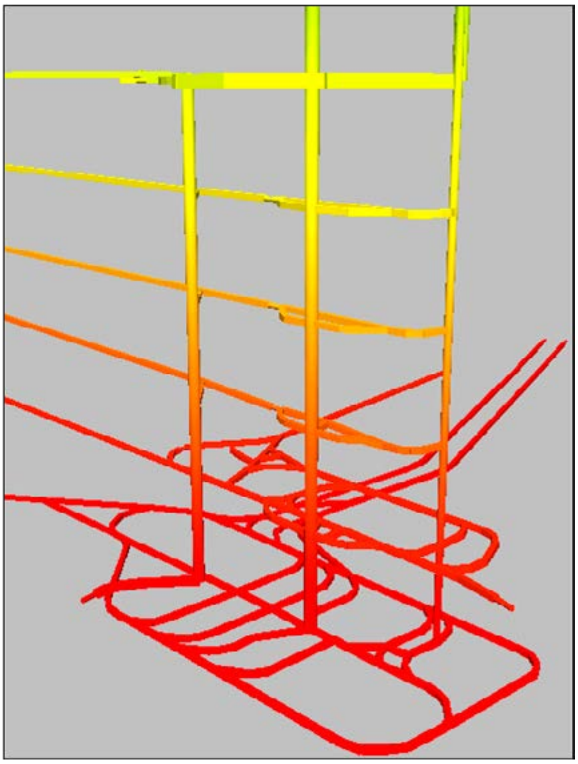


Figure 6: Example of underground haulage (2)

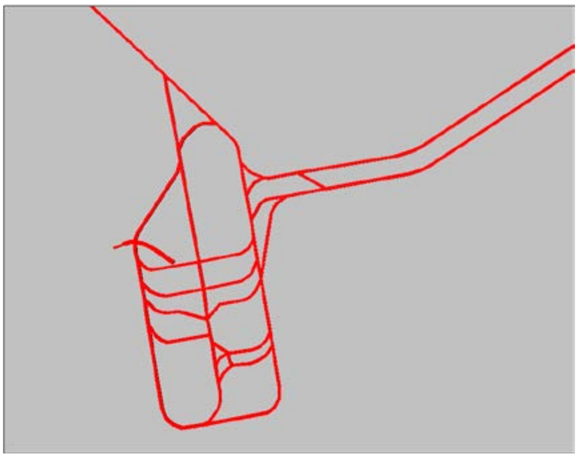


Figure 7: Example of underground haulage (3)

Figure 8: Example of underground haulage (4)

12. RE-UTILISATION OF ABANDONED MINES FOR UNDERGROUND PUMP STORAGE [13]

Based on theoretical ability:

- To flood large areas of the mine
- To operate large turbine-, pump-, and column infrastructure
- To operate pump storage between:
- Surface dam (i.e., not underground) and lower mine levels
- Upper mining levels and lower mine levels

Identified risk factors to resolve:
Geological risk factors:

- Geological formations of critical importance
- Water compartments
- Activity and pumping (fissure water) of adjacent mines
- Closing (collapse) of working areas and access ways

Technical risk factors:

- Larger infrastructure than typically employed by mines (pumps, turbines, and pressure columns –vertical transport of equipment)
- Sealing of catchment areas –preventing loss/gain of water
- Pyrite (FeS2) found in Witwatersrand area: Acidic environment
- AMD (Acid Mine Drainage) Extended operation, Increase in concentration, Impact on equipment

Legislative risk factors:

- Mining license issued to mining houses for mining
- Repurposing shaft for power generation
- End of life legal obligations and rehabilitation responsibilities.
- Detailed survey and specialist input required

Environmental risk factors:

- Environmental impact assessments during operation
- Control and discharge of water and Acid Mine Drainage (AMD)
- Rehabilitation at end-of-life costs and scope unknown Economic risk factors:
- Cost of care and maintenance for shaft barrel (known and continuous)
- Cost for development of pump storage infrastructure Unknown (incorporating all the risk factors as a minimum is required)

Identified risks to be resolved / quantified to determine the feasibility of the concept of a utility scale project.

13. FEASIBILITY – PHES/UPHES

The very deep gold mines in South Africa have excellent conditions regarding fall height and geology and thus constitute optimal places for storage of energy from pumped storage power plants. The conditions in the gold mines mean significantly reduced costs as the necessary components for implementing pumped storage power plants are already available.

Anglo American has indicated its intent to generate electricity through renewable underground pumped hydro-electric storage (Ruphes) systems using water from flooded, abandoned mines in South Africa to power its own local mining operations with renewable energy. Pre-feasibility studies into Ruphes systems are currently being undertaken.

14. CONCLUSION

The South African government has devised an urgent five-step action plan to address the ongoing energy crisis, by improving power station performance, accelerating new generation capacity procurement, increasing private investment, incentivizing commercial and residential solar adoption, and transforming the electricity sector. This plan would be incomplete if PHES is not considered.

Compared to Switzerland's latest hydro battery, PHES equates to a capital cost of less than R 1 800 / kWh whilst the current Eskom Battery Energy Storage Solution (BESS) project is estimated at R 8 200 / kWh.

Against international benchmarking, long term hydro-energy storage is generally more than three times cheaper than that of chemical batteries.

With innovation and re-utilisation of existing infrastructure the price of PHES/UPHES can become very competitive and help to achieve Grid stability in South Africa.

This explains China's extensive building program on PHES.

ANNEXURE A [2]

Name	Type	Energy [MWh]	Power [MW]	Generation Mode [h]
Ouarzazate Solar Power Station	Thermal storage, molten salt	3,005	510	3/7/7.5
McIntosh CAES Plant [de]	Compressed air storage, in-ground natural gas combustion	2,86	110	26
Cerro Dominador Solar Thermal Plant	Thermal storage, molten salt	1,925	110	17.5
Solana Generating Station	Thermal storage, molten salt	1,68	280	6
Moss Landing Energy Storage Facility	Battery, lithium-ion	1,6	400	4
Extresol Solar Power Station	Thermal storage, molten salt	1,125	150	7.5
Crescent Dunes Solar Energy Project	Thermal storage, molten salt	1,1	110	10
Andasol Solar Power Station	Thermal storage, molten salt	1,031	134.7	7.5
McCoy Solar Energy Project	Battery, lithium-ion	920	230	4
Manatee Energy Storage Center	Battery	900	409	2.2
Huntorf CAES Plant	Compressed air storage, in-ground natural gas combustion	870	290	3
Elkhorn Battery	Battery, lithium-ion	730	182.5	4
Slate Project	battery	561	140.25	4
Valley Center Battery Storage Project	Battery, lithium-ion	560	140	4
Victorian Big Battery	Battery, lithium-ion	450	300	1.5
Bokpoort CSP	Thermal storage, molten salt	450	50	9
Dalian VFB	Battery, vanadium redox flow	400	100	4
Alamitos Energy Center	Battery, lithium-ion	400	100	4
Saticoy BESS	Battery, lithium-ion	400	100	4

ANNEXURE B: WORLD STATISTICS 2022 PHES [2]

Country	Power Rating [GW]	Energy Storage [GWh]	Hour Generation [h]	In-stalled Power Ratio (%)
China	32	1646	51.4	20.6%
Japan	28.3	322.2	11.4	18.2%
United States	22.6	1074	47.5	14.5%
Spain	8	106.7	13.3	5.1%
Italy	7.1	117	16.5	4.6%
India	6.8	308.8	45.4	4.4%
Germany	6.5	204.1	31.4	4.2%
Switzerland	6.4	19.6	3.1	4.1%
France	5.8	129.3	22.3	3.7%
Austria	4.7	25.2	5.4	3.0%
South Korea	4.7	103	21.9	3.0%
Portugal	3.5	19.6	5.6	2.2%
Ukraine	3.1	56.9	18.4	2.0%
South Africa	2.9	56.6	19.5	1.9%
United Kingdom	2.8	94.6	33.8	1.8%
Australia	2.6	67	25.8	1.7%
Russia	2.2	263.5	119.8	1.4%
Poland	1.7	37.3	21.9	1.1%
Thailand	1.4	41	29.3	0.9%
Bulgaria	1.4	12.5	8.9	0.9%
Belgium	1.2	21.2	17.7	0.8%
TOTAL	**155.7**	**4726.1**	**30.4**	**100%**

ANNEXURE C: EXPERIENCE CURVE – ENERGY STORE TECHNOLOGIES

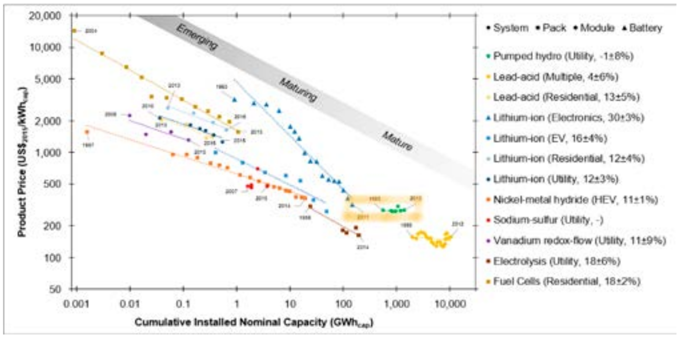


Figure 9:

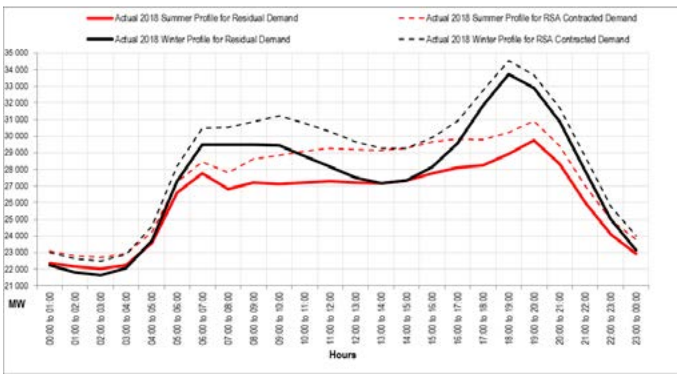


Figure 10:

15. ACKNOWLEDGMENTS

The authors thank the mining company Sibanye Stillwater, as well as BB Energy and M-Tech that were consulted, for the valuable information provided on UPHES.

Principal Author:

Ms Thea Naudé holds a National Diploma in Electrical Engineering Heavy Current from the Tshwane University of Technology. Thea started her career with Eskom in 1995 advancing from project engineering to senior advisor on key accounts. Since 2019 she is a specialist engineer at EHL whose duties, include among others, engagement with Eskom, NERSA and IPP's on behalf of Industry.

Co-author:

Mr Theunis Steyn holds a degree in Electrical Engineering from RAU, a B Com degree from Unisa and a BSc (Hon) Energy from RAU. Theunis started his career with Eskom in 1986 specialising on planning and design of electrical networks. Since 2003 he concentrated on aerial ropeway research and detail system design and project management thereof.

Presenter:

The paper is presented by Thea Naudé.

Address of authors:

Thea Naudé
Rietvlei Heights Country Estate
Centurion, 0157

Theunis Steyn
The farm Alkmaar
Nelspruit, 1200

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ENERGY EFFICIENCY THROUGH TECHNOLOGY, BEHAVIOUR CHANGE AND THE ROAD TO NET ZERO 2050

Martjie Cloete CEA, PMP
Western Cape Government Department of Health

ABSTRACT

The Western Cape Government Department of Health is committed to reducing the adverse impact healthcare has on the environment and has embarked on a series of energy efficient projects throughout the Province. All these projects are in line with the Provincial Climate Change Response Plan to achieve Net Zero Carbon emissions by 2050.

Technology Changes:
The Department has embarked on various projects to achieve the Net Zero 2050 goal. These projects include but are not limited to:

- **The de-commissioning of coal and oil-fired boilers in all but 4 facilities**
- **Retrofitting**
- **Waste heat recovery**
- **Replacement of inefficient equipment**

The Department aims to achieve further reductions by making use of an Energy Services Company (ESCo) by means of a shared savings programme which implements energy savings interventions at various facilities.

Behaviour Change:
The combination of energy efficiency interventions as well as behaviour change is the most effective way to reduce consumption. The Department creates awareness through regular internal communications and webinars.

Other Utilities:
Although the pledge to GGHH was Scope 2 reporting, utilities such as water and waste are managed mindfully to minimise the environmental impact.

The Race to Net Zero Carbon:
The Department aims to be Net Zero Carbon by 2050 and a Race to Zero plan has been developed and projects are being implemented to achieve zero Carbon emissions by 2050.

Summary:
Through change management, awareness creation and technology implementation, the Department will ensure that Healthcare is done without Harm.

1. INTRODUCTION

The Western Cape Government Department of Health became part of the Global Green Healthy Hospitals' community in 2015 and made a pledge to Health Care Without Harm to enter the Race to Zero in order to become Net Zero Carbon by 2050. All 51 Provincial Hospitals forms part of this pledge. Race to Zero is a global campaign initiated by the United Nations Framework Convention on Climate

Change to rally leadership and support from non-state actors for a healthy, resilient, zero-carbon recovery that prevents future threats, creates decent jobs, and unlocks inclusive, sustainable growth. It mobilises a coalition of leading net zero initiatives by cities, regions, businesses, investors, and universities. Race to Zero is inviting health sector participation through the Health Care Climate Challenge.

The Departmental pledge to be Net Zero Carbon is based on Scope 2 Green House Gas emissions. The pledge was made to reduce electricity by 10% by 2020, 20% by 2030, and to be Net Zero Carbon by 2050.

The first of these targets was achieved resulting in the Department being awarded with the Gold Award for Climate Leadership from Health Care Without Harm in 2021.

2. VISION FOR NET ZERO

The Departmental vision for Net Zero is based on the following four pillars:

- Plan, design and build operationally efficient and functional buildings
- Reduce operational energy usage in existing buildings
- Increase renewable energy supply
- Offset any remaining carbon

2.1 Plan, design and build operationally efficient and functional buildings

All hospitals are designed, constructed, operated and maintained in terms of the 5L's Agenda:

- Long life – to conserve energy and ensure sustainability
- Low Impact – to reduce or even eliminate the carbon footprint during construction
- Loose Fit – to ensure designs are flexible and adaptable in terms of the area and environment
- Luminous Healings Space to create an enlightened healing environment
- Lean Design - collaborated and integrated

The above L's must be applied to the design of new hospitals. However, to make substantial progress in the Race to Zero, the following additional requirements must be met to minimise the energy requirements:

- Correct orientation with optimal sun shielding
- Narrow floor plate to facilitate natural ventilation and lighting
- A building envelope that conserves energy
- High ceilings in public spaces
- Internal colour schemes that maximise the effectiveness of both natural and artificial lighting.

2.2 Reduce Operational Usage in Current Buildings

As there are more existing buildings than planned new facilities, this component will be the largest of the Net Zero Vision, with the most budget and effort focusing on ensuring energy efficient hospitals. As mentioned earlier, the ESCo is the main vehicle to achieve reduced operational usage in hospitals.

Remote metering has been installed at all 51 facilities and webinar training has been provided to facility managers. This will assist with the monitoring of afterhours night loads.

2.3 Increase renewable energy supply

Renewable supply could include Photovoltaic panels, wind turbines, hydrogen or even waste to energy.

Fifteen hospitals have been identified for solar projects. These installations will be grid tied and will aim to reduce the load, with storage to be added at a later stage. The fifteen identified facilities forms part of the ESCo programme and the installation of photovoltaic panels will form part of an energy efficiency roll out.

2.4 Offset any remaining Carbon

WCGH is not currently involved with trading Carbon Credits, however preliminary investigations with the Provincial Department of Agriculture and the Provincial Department of Environmental Affairs and Development Planning into the feasibility of biodiversity credits are underway.

3. ENERGY EFFICIENCY PROJECTS

Energy efficiency projects are currently underway at the following facilities:

- Red Cross War Memorial Children's Hospital
- Paarl Regional Hospital
- Eerste River District Hospital
- Beaufort West Hospital
- Brewelskloof Hospital
- Ceres Hospital
- George Hospital
- Harry Comay Hospital
- Knysna Hospital
- Mitchell's Plain Hospital
- Khayelitsha Hospital
- Mossel Bay Hospital
- Mowbray Maternity Hospital
- Vredenburg Hospital
- Worcester Hospital

These projects are in various phases of completion and the initial savings at Eerste River District Hospital is shown in the graph below:

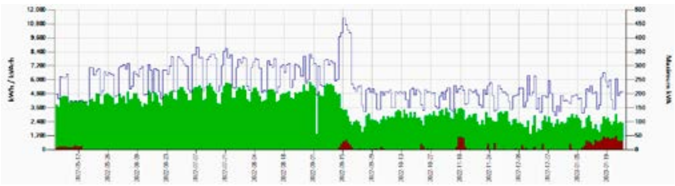

Figure 1: Savings at Eerste River Hospital

Savings of between 25% and 30% has been achieved at this site. Interventions such as lighting retrofitting, the installation of low flow showerheads and the optimisation of chillers and heat pumps were done.

Water Savings

The ESCo has also been appointed to do water savings and preliminary investigations are underway to determine shared savings opportunities.

4. BEHAVIOUR CHANGE

Training, empowering and sensitising employees are done by means of the following:

- Infographics
- Webinars
- ESCo

The infographic below was distributed by means of the internal communication:

Figure 2: Creating Awareness

A series of webinars is currently underway to create awareness around Climate Change as well as being conscious of electrical consumption. The first of these webinars was focused on the Provincial Climate Change Strategy developed by the Provincial Department of Environmental Affairs and Development Planning.

A Scope 2 Carbon footprint tool was developed by the Department of Environmental Affairs and Development Planning and internal software development was done to incorporate this tool into the Departmental reporting software. This will enable facilities managers, financial managers as well as hospital CEO's to track consumption as well as determine the monthly cost.

5. LESSONS LEARNED

The following lessons were learned on the current Net Zero journey:

- Small actions make a difference, if 33 000 employees can just switch off one light it will result in a R6million saving
- Ensure that the consumption is captured and monitored at all facilities and where possible, install remote metering
- Do the basics right – fix infrastructure, switch lights off
- Old buildings are not necessarily energy guzzlers it is how you manage it
- The right ESCo partner can greatly assist you to achieve your goals

6. CONCLUSION

The Department is committed to reducing energy and the reduction targets forms part of the Annual Performance Plan against which the Departmental performance is audited and is on track to reduce consumption by a further 10% by 2030.

Principal Author:

Martjie Cloete holds a Hons BCom Financial Management degree from the University of Pretoria. At present she is the Climate and Utilities Champion at the Western Cape Government Department of Health.

ENERGY EFFICIENCY MANAGEMENT SYSTEM AT SASOL

Rajiv Tedpaul and Johan Kruger
Sasol Energy Operations, Production Improvement, Energy Efficiency Sasol, Energy Sustainability and Strategy

1. ABSTRACT

This paper is an overview of Sasol's energy management system (EnMS), aimed at improving the energy efficiency performance with a focus on current activities and future improvements.

Comprehensive energy efficiency (EnEf) management and performance reporting began to gain meaningful traction in South African industries from 2005, with the South African Energy Accord, thereafter followed by the National Energy Efficiency Strategy (NEES) issued by the Department of Energy which sets a target of 15% reduction in energy intensity for industry by 2030, from 2015. This is in addition to the previous target of 15% reduction from 2000 to 2015 set under the South African Energy Accord.

Sasol has several operational sites in South Africa and abroad which include continuous and batch processes; petrochemical; refining; coal mining and drilling operations. The disparate nature of each of these operations has presented an opportunity to employ innovative performance evaluation techniques where conventional methodologies cannot adequately address the challenges of consolidation into a coherent performance metric.

Data collection, analysis and performance reporting according to a comprehensive energy management system according to the guidelines of ISO 50001, forms the basis of the focus areas discussed. Continuous improvements in the practice of energy efficiency management principals include:

- **daily performance monitoring tools;**
- **improvement initiatives;**
- **community of best practices;**
- **mentoring and coaching of EnEf principals**

2. INTRODUCTION

Sasol uses energy to produce and distribute our products to various markets. Fossil fuel energy used in the processes is a finite resource, the activities of which have an impact on people, planet and profit. We strive to continuously improve the performance of all the manufacturing operations in support of the following drivers:

- To save operating costs;
- To contain and reduce the environmental footprint of our operations;
- To support national energy conservation initiatives and objectives.

Sasol's scope 1 and 2 emissions are a challenge, for the Southern African value chain, where the largest portion of greenhouse gas emissions (GHG) are concentrated. We aim to achieve GHG reduction with a combination of levers including transitioning to lower carbon feedstocks, renewable energy and process efficiency projects.

- For renewable energy we plan to procure around 1200 MW in tranches by 2030, starting with 600MW in partnership with another company.
- Our energy efficiency drive is centered around our integrated plan to meet air compliance targets for our steam boilers while also reducing GHG emissions. This will be enabled by turndown of our own coal-based steam and power generation and replacement of this with renewable energy and energy efficiency projects.
- The turndown of the boilers will be enabled by a host of energy efficiency projects that maximize the use of latent heat from our processes to produce steam.
- This roadmap includes the fine coal solutions to manage the excess fine coal gap that is created by the boiler turndown. As technologies becomes cost attractive, we will also leverage steam to electric drive conversions; variable steam drives to utilize our energy more effectively; new technology development in more efficient electrical machinery; and continuous improvement of our energy management systems to world class standards in support of optimization of our operations.

Sasol utilizes EnEf management principles as an integral part of our daily operations by reporting on energy efficiency performance for all operational sites on a monthly basis, with the aim of reducing our carbon intensive footprint and to deliver upon our long-standing commitment to promoting energy efficiency as a key business driver, in addition to the benefit of reducing GHG emissions. Sasol is in support of the National Energy Efficiency Strategy for 2030 (NEES 2030), for which we have set a challenging objective to exceed the 30% target.

3. SASOL ENERGY MANAGEMENT SYSTEM

3.1 The Sasol energy management system is designed and structured around the following key principles:

a) Continuous Improvement
- Energy roadmaps and improvement initiatives
- 12L tax incentive processes

b) Data management and reporting
- EnEf data bases and automated energy reporting system
- Microsoft Power BI visualization of performance on a standard platform
- Data management systems utilizing Asset Framework; Microsoft K2; Honeywell and Aspen Technology

c) Standards and assurances
- Community of best practices
- Documentation of policies and procedures
- Compliance and assurance of the energy management system

d) Stakeholder commitments
- Internal stakeholder commitments and reporting
- Standardization of EnEf principals within the organization
- External stakeholder objectives (EP100; South African Department of Energy)

These key principals form the nexus of a series of support-

ing inputs and performance objectives that underpin the success of the company's energy management system.

4. ENERGY EFFICIENCY IMPROVEMENT

Sasol utilizes a range of energy carrier streams, referred to as Key Performance Indicators (KPI's). Manufactured products are usually produced via a chain of processing plants or value chains, situated within specified geographical areas namely, Secunda, Sasolburg and various smaller satellite operations around the various provinces within South Africa.

All energy streams have been standardized to the gigajoule (GJ) unit of measure, according to international convention. This, in addition, is due to the consumption of the combined weighting of the primary energy streams (fossil fuels) being higher than that of electricity, for which the Kilowatt. Hour (kWh) is normally the acceptable unit of measure.

4.1 Calculation of Energy Efficiency performance

4.1.1 Chemical processing plants

Cumulative energy (GJ) and net production (ton) data is collated on a monthly basis, where it will be verified for accuracy according the quality reporting procedure. Any adjustments and consolidation to the reported data will then be performed prior to submission to the electronic data management system, designed on the K2 (Microsoft software program) platform.

$$Energy\ Intensity\ (EI) = \frac{Energy\ consumed}{Net\ Production} \qquad (1)$$

where,
Energy intensity (EI) is in GJ/ton
Total energy consumed is in GJ
Net production is in tons

4.1.2 Calculation of Mining Energy Efficiency Performance

Targets for our Mining operations are based upon energy savings achieved from improvement initiatives implemented from the baseline year and accumulated on an annual basis against actual energy consumption recorded from the baseline year. (1)This approach is based upon a synthesis of an energy intensity index instead of an energy intensity ratio, because neither specific energy consumption (energy per ton of coal mined) nor energy intensity (energy per ton of coal output) is a satisfactory proxy measure for energy efficiency in the coal mining industry. Furthermore, this is based upon the inherent nature of mining activities constantly progressing further away from a common processing area and requiring more electrical energy to move the coal.

$$Mining\ Operations\ EIi = \frac{Baseline\ energy\ consumption - \Sigma\ energy\ saving\ improvements}{Baseline\ energy\ consumption} \qquad (2)$$

Table 1: Sasolburg Operations energy consumption

	Baseline year 2015	Financial Year 2021	Financial Year 2022
Energy Intensity (GJ/ton)	23.23	19.06	19.92
EnEf performance from baseline		17.9%	14.2%

a) An improvement can only be recorded if the EI for the period under review (financial year) is lower than the EI of the baseline year.
b) We refer to the ratio of this comparison as the Energy Intensity Index (Eli)

$$Energy\ Intensity\ Index(EIi) = \frac{EI\ of\ period\ under\ review}{EI\ of\ baseline\ year} \qquad (3)$$

Table 2: Typical primary energy sources utilized at the Sasolburg Operations site

Energy KPI	Consumption
Electricity purchased	Purchased from external supplier (Eskom) and converted to the primary energy source using the appropriate emission factor
Electricity export	Electricity generated by Sasol and exported into the electricity grid
Feed to Electricity	Coal used as the primary source
Feed to steam	Coal used as the primary source
Fuel gas	Natural Gas blended with hydrogen
Transport fuel	Petrol and Diesel used in vehicles
Stationery fuel	Petrol and Diesel generators and pumps
Other energy	Fuel Oil used in the steam boilers

4.2 Energy Efficiency performance

$$EnEF\ performance\ (\%) = \left(1 - \frac{EI\ of\ period\ under\ review}{EI\ of\ baseline\ year}\right) \times 100 \qquad (4)$$

- Sasol Group operational sites include:
- Sasolburg Operations
- Secunda Operations
- Natref Operations
- Regional Operations & Asset Services
- Mining Operations
- Chemicals Eurasia
- Chemicals Americas
- Gas Supply Operations

Table 3: Consolidation of Sasol operational sites for financial year 2022

	Energy Intensity (GJ/Ton)	Energy Intensity Index (Eli)	Improvement from baseline
Sasol Group EnEf Performance	15.325	0.981	1.9%

Table 3 shows the consolidated EnEf performance data of all operational sites listed in 4.3 above, expressed as a percentage of improvement from the baseline. The Eli based upon equation [3] expresses the ratio which indicates an EnEf improvement if it is lower than 1.0 or an EnEf regression if greater than 1.0.

4.4 Application of energy weighting factors

The energy intensity ratio for each operational site is weighted according to the distribution of energy consumption as a fraction of the company's total energy consumption on a monthly and annual basis. Practice has shown that the application of energy weighting factors highlights those sites with a significantly higher energy footprint and their

contribution towards the overall EnEf performance of the company.

$$\textit{Sasol Group EnEf performance} = \sum_{i}^{n} x \ (\textit{ELi} \times \textit{Energy weighting factor}) \quad (5)$$

4.5 Baseline Adjustments

Baseline adjustments to the EI ratio are conducted whenever there is a fundamental change to the asset of an operational site, affecting the net production output. This could be due either to expansions or downsizing of a facility; divesture either in part or the whole of a facility for business reasons; and seasonal demand changes.

$$\textit{Adjusted baseline} = \frac{(\textit{original baseline energy} - \Delta\, \textit{energy})}{(\textit{original baseline net production} - \Delta\, \textit{net production})} \quad (6)$$

While it is common practice to make baseline adjustments at the beginning of a financial year, it can happen that a change in operations occurred during the course of a financial year, thus requiring a combination of the original and new baselines to produce a consolidated baseline. In such a case a transitional baseline is calculated based upon a monthly weighted ratio for each month till the end of the current financial year, while a new absolute baseline ratio for the new financial year will take effect from the first month of the new financial year.

$$\textit{Transitional baseline adjustment} = \sum_{i=1}^{12} \left(\frac{(\textit{baseline energy} \times i) + (\textit{adjusted energy})(i+1)}{(\textit{baseline net prodn} \times i) + (\textit{adjusted net prodn})(i+1)} \right) \quad (7)$$

Where i represents the last month of the original baseline.

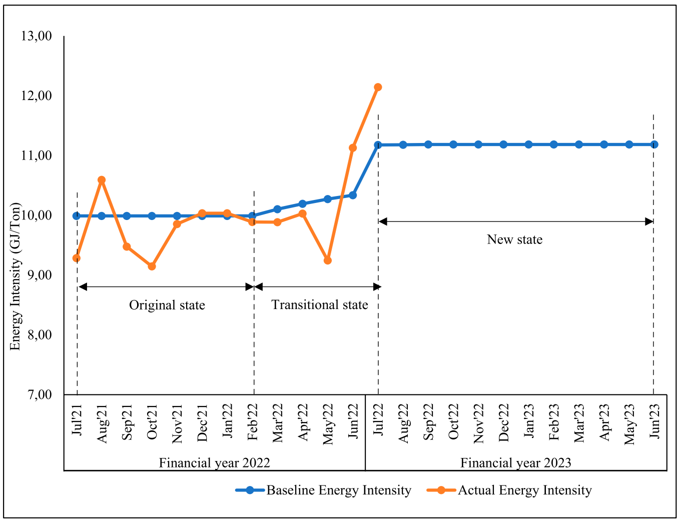

Figure 1: Consolidation of baseline adjustments

Figure 1 represents a baseline adjustment scenario at the Chemicals Eurasia operations, to cater for the sale of the Wax manufacturing site effective from February 2022, thus necessitating an adjustment to the state of the EI baseline using equations (7) and (6) respectively. The transitional baseline adjustment till the end of the financial year using these equations has also been programmed into the Microsoft K2 data reporting program to ensure accuracy of the monthly and annual EnEf performance of the business. The new financial year commencing from July 2022 will then represent the absolute baseline adjustment, barring any additional fundamental changes to the asset of the business.

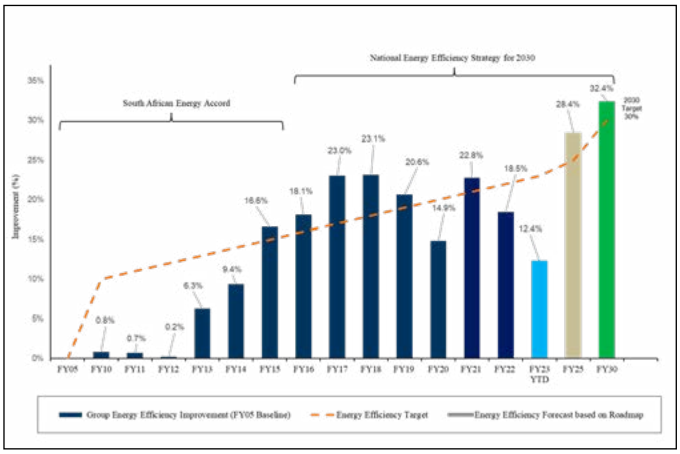

Figure 2: Historical performance and forecast

The historical performance and forecast graph shown in Figure 2 shows the company's EnEf performance landscape from financial year 2005 until 2022. A total EnEf improvement of 16.6% was achieved from the 2005 financial year under the South African Energy Accord (2). From financial year 2015, under the National Energy Efficiency Strategy (1) the cumulative energy efficiency improvements (including that which was achieved until financial year 2015) has fluctuated due to multitude of internal and external influences. The forecasted improvements until financial year 2025 and 2030 is derived from the company's energy improvement roadmap comprising a list of initiatives and capital-based solutions, geared towards reaching the goal of a 30% EnEf savings target.

5. ADVANTAGES OF THE ENMS

The Sasol EnMS since implementation, has demonstrated immense benefits by showing genuine EnEf improvements from the baseline year. This has been further supported by the larger operational sites actively developing, monitoring and reporting on improvement initiatives as part of their respective EnEf roadmaps to achieve the company's objectives. Stakeholder reporting of EnEf performance has also been facilitated due to automation of the EnMS reporting platform and the three levels of quality control and accuracy of the data reported. The visualization of the monthly EnEf performance in Microsoft Power BI has enabled management firsthand insight into the performance of their sites and potential areas for improvement. This has been further enhanced by the software's ability to granulate and inspect data at a level of individual unit operation.

6. CHALLENGES AND AREAS FOR IMPROVEMENT

a. While the practice and reporting of energy data throughout the organization has been steadily improving, it has been shown that new employees moving into the field of EnEf tend to adapt much more easily with the data reporting systems and changes in technology. However, insights into generating operational EnEf improvement ideas from a conceptual perspective is much more prevalent with more experienced technical and operations personnel.
b. During the implementation phase of the energy management system, there was a high rate of resistance in adopting the automated reporting system due to changes in work practices. This was however alleviated with coaching and improvements in training material.
c. Legacy data sets were of a poor quality which often

needed to be re-stated due to the lack of quality control systems and limited management oversight. This became especially apparent when access to original data sources was extremely limited, due to outdated document management systems.

d. Resources required to take ownership of a sites EnEf reporting responsibilities was limited and required engineers and other support personnel to take on the additional responsibility in the maintenance and upkeep of their EnMS. This challenge was usually encountered at the smaller sites, which often did not have an appointed energy representative.

7. ENERGY EFFICIENCY AND GHG REDUCTION

Sasol is committed to accelerating our transition to a low carbon world in support of the objectives of the Paris Agreement. We are acting on our commitment to reduce our GHG emissions by 30% by 2030 which lays a foundation for achieving a net zero ambition by 2050. Our 30% reduction plans to 2030 will leverage known solutions and technologies and can be delivered with optimal capital investments.

Beyond 2030, we have more than one viable pathway to get to our net zero ambition by 2050, with different options to transform our Southern Africa value chain – progressively shifting our feedstock away from coal, towards more transition gas, and then, green hydrogen and sustainable carbon over the longer term – as their economics improve. In an uncertain future, this approach offers agility and enables us to pivot as cost effective mitigation levers become available. Today we have almost all of the commercial scale kit needed for this production. Our Fischer Tropsch process is feedstock agnostic and we can progressively move towards a future without fossil fuels and emissions. Through the incremental introduction of green hydrogen, we can produce sustainable products in South Africa. Our scope 1 and 2 emissions are a bigger challenge, for our Southern African value chain, where the largest portion of our greenhouse gas emissions are concentrated. We aim to achieve this GHG reduction with a combination on levers including transitioning to lower carbon feedstocks, renewable energy and energy and process efficiency projects. With technology and efficiency improvements in our process, we are confident that we will achieve the full 30% target by 2030.

For renewable energy we plan to procure around 1200 MW in tranches by 2030, starting with 600MW in partnership with Air Liquide. Our energy efficiency drive is centered around our integrated plan to meet air compliance targets for our steam boilers while also reducing GHG emissions. This will be enabled by turndown of our own coal-based steam and power generation and replacement of this with renewable energy and energy efficiency projects. The turndown of our boilers will be enabled by a host of energy efficiency projects that maximize the use of latent heat from our processes to produce steam. Our boilers utilize fine coal, an unfortunate co-product we get when we mine for process coal. Our roadmap includes the fine coal solutions to manage the excess fine coal gap that is created by the boiler turndown. As technologies become cost attractive, we will also leverage steam to electric drive conversions, variable steam drives to use our energy effectively, new technology development in more efficient electrical machines, integrated into our world class energy management systems to optimize our operations.

As a proudly South African business, focused on delivering sustainable solutions for customers, we believe we can both assist the country to decarbonize, while seizing upon the significant business opportunities the energy transition has to offer. Our strategy is ambitious, but it is grounded in realism for which we are confident that we will deliver upon.

8. CONCLUSIONS

a. The evolution of the Sasol energy management system and EnEf reporting is proving to be a powerful tool in driving, monitoring, reporting and demonstrating the path to the achieving the target of 30% energy savings by 2030 in addition to forming the basis of reducing our carbon footprint towards our journey to being a carbon net zero organization by 2050.

b. Energy efficiency principles are currently being incorporated into engineering design principles and into existing and new unit operations. This is also being included as a prerequisite where practical, in the procurement of goods and services.

c. EnEf themes and awareness has been identified as a key lever in driving a culture of maximizing the efficiency of our natural resources and reducing our carbon footprint. A concerted effort through training and roadshows is being made to highlight the importance of EnEf as one of the key drivers in the future sustainability of the organization.

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3. Johan would like to acknowledge Annalise Louw for her guidance and knowledge in the development of the Sasol GHG roadmap geared towards the Sasol target.

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AUTHORS(S)

Principal Author:

Rajiv Tedpaul has extensive experience in petrochemical operations at Sasol Energy Operations and held various roles throughout his career. He is an Energy Efficiency Specialist within the Operations Improvement team and a key member of the team responsible for the functionality of the EnMS reporting system; data analytics and energy efficiency performance reporting, in support of Sasol's energy efficiency savings targets.

His previous experience includes process & production engineering; project management and Process Safety Management (PSM).

His engineering background includes a B (Chem Eng.); Certified Energy Manager (CEM) and an active member of the SAEEC and the international Association of Energy Engineers (AEE).

Co-Author:

Johan Kruger is the Principal Specialist Environmental Portfolio for Sasol energy. He is a chemical engineer and has more than 15 years' work experience including substantial experience in sustainability studies for Sasol.

He has a wide range of experience from plant operation and production, capital projects and research and technology management. Through his different roles in the company he has an excellent understanding of Sasol's complex sustainability's challenges. He has developed a wide knowledge base of both air, water, waste, GHG, product stewardship other ESG aspect of Sasol's sustainability roadmap for South Africa. This included development of our sustainability roadmaps in an agile environment to support Sasol GHG target setting objective resulting in the pathways that will see Sasol energy achieve a 30% GHG reduction by 2030 and net zero ambition by 2050.

POWER QUALITY IN SOUTH AFRICAN INDUSTRY

Tanya van Zyl
Quality Manager (NCPC-SA)

ABSTRACT

Power Quality (PQ) as a field of study investigates disturbances in voltage and current waveform, unbalance, voltage regulation and the frequency of a power supply. In South Africa, the NRS048 set the technical specification to the minimum requirements in voltage quality (the quality of supply).

When PQ disturbances occur; these could cause malfunctioning of electrical equipment at industrial manufacturing facilities. For example, when a voltage dip occurs, sensitive equipment can trip leading to production line stoppage. Lost product and productivity resulting from poor PQ served to end-users, contributes to operational, business and even reputational risk in South Africa.
Poor Power Quality is a growing phenomenon internationally but emphasised in South Africa by the lack of performance at electrical utilities to serve end-users with voltage at the minimum technical requirements. The sophistication in energy conversion at renewable energy sources and at end-users using solid-state interfaces such as inverters to inject energy or Variable Speed Drives (VSD) to consume electricity in a controlled manner, further contributes to a concern on voltage quality in general.

Other causes of poor Power Quality include events such as lightning strikes, birds on powerlines, the starting and stopping of heavy equipment, circuit overloads or even improper wiring to name a few [1].

The NCPC-SA assists South African industry with assessing PQ and identifying solutions to improve business risk resulting from consuming electricity. A high-level business case on the specific mitigation solution is presented. This paper presents the results of case studies where the NCPC-SAs supported South African industry.

Key words: Power Quality, Mitigation, Electricity, Voltage quality, Dips, Swells, Harmonics, Unbalance, Flicker.

1. INTRODUCTION

Power Quality refers to the quality of voltage supplied to an end user/customer or electrical equipment. Figure 1 below presents a general classification of Power Quality parameters.

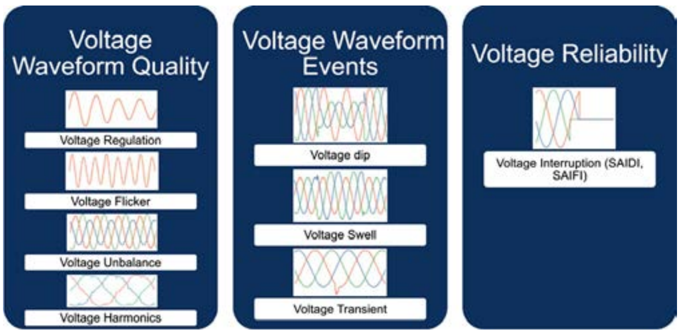


Figure 1:Power Quality Disturbances [2]

Electrical equipment is designed to have immunity against PQ disturbances that should enable them to perform as designed when subjected to a certain level of disturbance in PQ. The concern on PQ is realised when electrical equipment malfunction or fail when the PQ immunity level is exceeded.

Countries and regions have adopted PQ standards that describe the minimum level in PQ at end-users and how to benchmark field data against these requirements. In Europe for instance the EN 50160 applies, while in the Southern and East African region the NRS 048 part 2 document is the regulatory standard that helps to harmonise PQ benchmarks in the interconnected regional network.

The electrical utility is responsible for taking care of voltage quality up to the Point of Connection (PoC) to end-users. Downstream of the PoC, it is the responsibility of the end-user to ensure that the degradation of PQ is not beyond the immunity level of electrical equipment.

An electrical utility has control over some aspects that affect PQ:

- Maintenance of infrastructure: cleaning of insulators, servitudes, scheduled maintenance of tap-changes, transformers etc.
- Network operation: loading of lines and transformers, voltage control, grounding, and protection settings.
- Planning and budget applications: upgrading of network capacity accounting for load growth and end-of-life scenario.

Whilst the electrical utility takes responsibility for voltage quality, end-users (consumers and sources of mostly renewable energy) have an important impact on current quality. If they for example consume or inject harmonic currents, voltage harmonics are realised across the utility supply network impedance, consequently affecting the voltage total harmonic distortion at other points in the interconnected network.

Selling electricity such that all end-users remain to be served by the minimum levels in voltage quality therefore requires that all users of the supply network need to contain their impact to not compromise the ability of the utility to remain serving all end-users well.

The National Energy Regulator of South Africa (Nersa) was mandated by government to protect the interest of the buyer and seller of electricity through measures such as licensing conditions requiring suppliers of electricity to have a Power Quality Management System (PQMS) operational. Using the NRS 048 as reference, licensees should have visibility on the voltage quality within their network and why both planning, and compatibility levels are defined in the NRS 048. This allows utilities to intervene when PQ degrades beyond the planning level, avoiding serving end-users beyond the compatibility level.

Compatibility considers the aspects of technical feasibility and economic feasibility when PQ within a network is investigated. It is not possible to manufacture equipment immune to all disturbances or to prevent all PQ disturbances on a network and therefore emission (of disturbances)

limits are agreed (through contracting) with consumers of electricity.

Figure 2 illustrates the concepts of planning levels, compatibility levels and immunity levels. The Y-axis indicates the probability density while the X-axis indicates the level of disturbance. The illustration can apply to any of the PQ disturbances. System disturbance levels are shown as a normal distribution curve towards the left of the graph. The higher levels of disturbance cross the planning levels as well as the compatibility level and even into immunity test levels. Equipment immunity levels describes the level of disturbance for which a particular piece of equipment should be able to operate within specifications. The compatibility level is therefore the disturbance level at which compatibility should exist for most equipment. Compatibility levels exist below equipment immunity levels to allow for short periods of higher disturbance. Network planning levels are set below compatibility levels to avoid complaints and equipment failures.

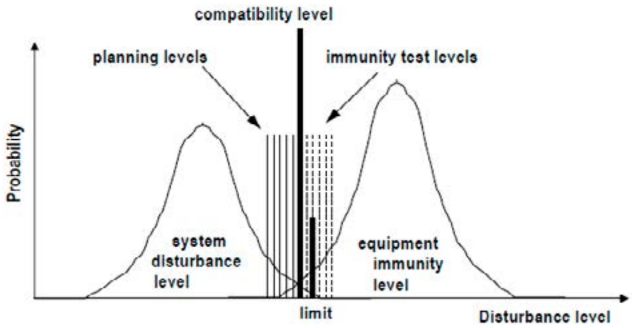


Figure 2: Illustration of Compatibility concept [3]

If a supply network has sufficient fault level, the low impedance towards end-users will contain the impact of poor quality in current consumption on the supply network voltage quality. Network capacity is mostly limited in South African networks due to long lines (high impedance) and highly loaded transmission and distribution equipment.

It is possible to contain the impact of end-users on voltage quality by setting limits on harmonics, unbalance, and flicker emission. Initially, such PQ clause in a supply contract was only negotiated with large consumers. Nowadays, distorting customers are all over and in all sizes, even residential customers having inverter-controlled cooling (fridges, air-conditioners) and heating (heat pumps) equipment and in rooftop solar electricity.

A well-known PQ concern is a voltage dip event. A single dip event could cause strategic electrical equipment (such as computerised automation) to interrupt production. From the utility's perspective, supply reliability was not affected as the voltage supply was not interrupted however, from the end-user perspective, the voltage dip event constitutes an interruption. The dip performance of the network is therefore usually worse compared to what the supply reliability or recorded supply interruptions would indicate.

In certain industries such as the food industry, re-work of the product is not possible. Each interruption in production due to a voltage dip causes permanent product loss. This is exacerbated by the fact that many companies already operate 24/7, which means that production cannot be caught up if production levels cannot be scaled up. The loss in production and product is a permanent financial loss, and sometimes also a reputational loss when promises in delivery to clients cannot be honoured.

Different industries are affected differently by voltage dips. A final example is the mining industry where a ventilation fan can cause production to come to a complete standstill when it trips (due to a voltage dip) necessitating the evacuation of underground personnel until the integrity of the fans have been confirmed [2].

The National Cleaner Production Centre of South Africa's (NCPC-SA) mandate is to support industry to transition to a lower carbon economy through application of Resource Efficient and Cleaner Production (RECP) methodologies. One of the NCPC-SA projects was to develop a suite of Power Quality training courses aimed to increase awareness, knowledge, and skills at the South African manufacturing industry on addressing the growing concern on South African PQ.

A 2-day (16 hour) course on fundamental principles of PQ for end-users in electricity and an expert course starting with a 4.5 days (36 hour) contact session at a "host site" were developed.

The host site serves to practically demonstrate the assessment of Power Quality at an industrial site through measurement with PQ instruments (supplied by NCPC-SA) installed at points of interest. Field data is analysed and discussed during the expert course. Having completed the host site session, candidates are then expected to perform a Power Quality assessment at their own sites with the assistance and mentoring of the lead facilitator. The site management are then provided with feedback on the PQ assessment and what potential solutions can be considered to improve their business risk resulting from PQ.

The Expert Training course was delivered at two host sites since 2020:

- BMW Rosslyn
- Atlantis Foundries, Atlantis, Cape Town

Next, the paper discuss the methodology and results obtained by presenting a PQ expert training course at Atlantis Foundries.

2. HOST PLANT ASSESSMENT METHODOLOGY

Atlantis foundries (PTY) Ltd. hosted the second PQ expert training course. NCPC-SA supplied and installed 3 PQ instruments and had Atlantis plant personnel attending the training, all at no cost to the company.

2.1 Determining the Scope and Boundaries

PQ instruments were installed at selected supply points within the Atlantis Foundries network two weeks prior to the course. Data was collected to:

- Validate the performance of an existing Active Harmonic Filter (AHF).
- To assess and benchmark PQ at their PoC to the supply network.
- To determine the impact on PQ within the internal Atlantis Foundries distribution network as contributed by downstream loads such as their furnaces.

The Atlantis Foundries have different divisions from melting metal and casting to finally supply engine blocks to a separate facility that take care of final machining.

A significant source of harmonic currents are the 12-pulse rectifiers at the DC furnaces.

2.2 Field Data

The NCPC-SA supplied GPS synchronised VECTO III PQ instruments. Data was hosted in a Cloud-base PQ database, www.ospreypro.com, also used for data analysis and reporting.

Three of the seven feeders to Atlantis Foundries were monitored:

- William Gourlay 1 (Melting furnaces)
- William Gourlay 2 (Furnaces without AHF)
- William Gourlay 5 (Furnaces with AHF)

Electricity is distributed by a ring feed to the different furnace sections.

2.3 Data Analysis

The following general conclusions were made:

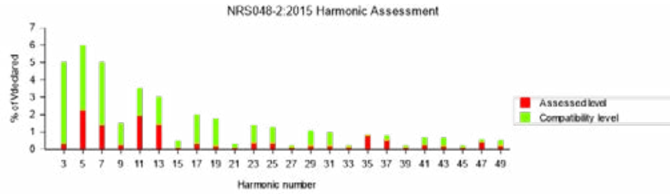
- The electrical utility supplied voltage fully compliant to the minimum requirements of NRS048:2015 on the regulation of voltage magnitude, unbalance, flicker, and total harmonic distortion.
- Individual voltage harmonic components 35 and 39 in the William Gourlay 2 feeder were not compliant to the compatibility requirement of NRS048:2015. Their contribution to the voltage Total Harmonic Distortion (THD) were negligibly small. Voltage THD is quantified by the ratio of all voltage harmonic components (Vh) to the fundamental frequency component (V1):
  - $$Voltage\ THD(\%) = \frac{\sqrt{\sum_{h\neq 1}^{N} V_h^2}}{V_1} \times 100$$
- As no evidence of further harmonic resonant amplification was noted and with the amplitude of these two harmonic components relatively small, it was concluded that the 35th and 39th voltage harmonic is of no immediate concern.
- Only 3 Y-type dips were recorded with no impact on production equipment.
- Atlantis foundries is situated near Koeberg nuclear power station, a benefit to the dip performance of distribution networks in that area.

Figure 3 and Figure 4 present the NRS048 assessment of individual voltage harmonics recorded at William Gourlay 5 (equipped with active harmonic filters at the production plant) and at William Gourlay 2 (without active harmonic filters at the production plant).

All individual voltage harmonics at William Gourlay 5 were compliant to the NRS 048 part 2 compatibility requirements, validating the successful performance of the active harmonic filters. At William Gourlay 2, only the individual voltage harmonics 35 and 39 were found to be non-compliant to the NRS 048 part 2 requirements.

- With all feeders sharing an interconnected network, the relative low voltage harmonics at William Gourlay 2 benefit from the AHFs at William Gourlay 5. The reason why the 35th and 39th voltage harmonic is non-compliant is most probably due to the AHF itself having the ability to increase certain current harmonics upstream, being a solid-state power electronic device.
- Note that an AHF injects harmonic currents out-of-phase to compensate for load-generated harmonic currents.

[1] Compliant to IEC 61000-4-30 Class A edition 3 requirements on both voltage and current.



Uneven Harmonics

Order	Criteria	Value	Result
5	6.00	2.25	Pass
7	5.00	1.37	Pass
11	3.50	1.93	Pass
13	3.00	1.44	Pass
17	2.00	0.32	Pass
19	1.76	0.20	Pass
23	1.41	0.39	Pass
25	1.27	0.37	Pass
29	1.06	0.21	Pass
31	0.97	0.22	Pass
35	0.83	0.81	Pass
37	0.77	0.55	Pass
41	0.67	0.24	Pass
43	0.63	0.19	Pass
47	0.55	0.40	Pass
49	0.52	0.23	Pass

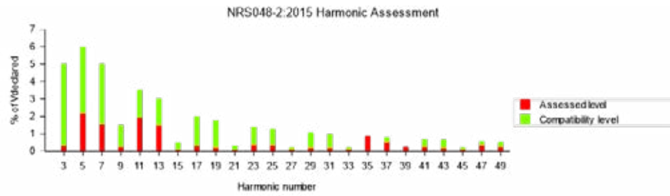
Triplen Harmonics

Order	Criteria	Value	Result
3	5.00	0.30	Pass
9	1.50	0.23	Pass
15	0.50	0.11	Pass
21	0.30	0.08	Pass
27	0.20	0.14	Pass
33	0.20	0.18	Pass
39	0.20	0.15	Pass
45	0.20	0.13	Pass

Even Harmonics

Order	Criteria	Value	Result

Figure 3: William Gourlay 5 NRS048:2015 Harmonic Assessment [4]



Uneven Harmonics

Order	Criteria	Value	Result
5	6.00	2.20	Pass
7	5.00	1.58	Pass
11	3.50	1.92	Pass
13	3.00	1.50	Pass
17	2.00	0.29	Pass
19	1.76	0.22	Pass
23	1.41	0.39	Pass
25	1.27	0.35	Pass
29	1.06	0.20	Pass
31	0.97	0.21	Pass
35	0.83	0.87	Fail
37	0.77	0.56	Pass
41	0.67	0.24	Pass
43	0.63	0.19	Pass
47	0.55	0.36	Pass
49	0.52	0.26	Pass

Triplen Harmonics

Order	Criteria	Value	Result
3	5.00	0.33	Pass
9	1.50	0.24	Pass
15	0.50	0.11	Pass
21	0.30	0.08	Pass
27	0.20	0.14	Pass
33	0.20	0.16	Pass
39	0.20	0.23	Fail
45	0.20	0.14	Pass

Even Harmonics

Order	Criteria	Value	Result

Figure 4: William Gourlay 2 NRS048:2015 Harmonic Assessment [5]

The impact on operations at Atlantis Foundries are discussed next.

2.3 Impact Of NCPC-SA on Operations at Atlantis Foundries

The awareness, skills and knowledge of the candidates were increased on PQ in particular, the Atlantis Foundries candidate was able to assess their PQ and to support initiatives within the company.

Atlantis Foundries added additional active harmonic filters at Willliam Gourlay 2 to improve the voltage THD and to contain all individual voltage harmonics to lower levels.

The value of having visibility on the quality of the electrical energy supplied by the supply and on the consumption of electricity within the plant, was realised by Atlantis Foundries and 9 permanent PQ instruments were installed at strategic points.

PQ data were also found useful in the design and specification of a 9.6 MW rooftop solar installation.

3. CONCLUSION

Electrical PQ has a wide-reaching impact on the South African economic growth. The NCPC-SA is supporting local SA industry to improve their knowledge and skills that could benefit businesses and reduce operational risk.

By presenting a course on the fundamental principles of PQ to end-users and empowering businesses in the application of that knowledge through skills developed during the expert course, some positive impact is already observed at participants.

End-users of electricity has a right to be served with a minimum level in PQ but also has responsibility to not affect the ability of the electrical utility to serve other users on the network with at least a minimum level in PQ by injecting an unacceptable level of PQ disturbances. These rights and responsibilities are described in the South African regulatory document, the NRS 048 part 2-2015. It also stipulates the principles of acquiring field data and how to benchmark the PQ performance of supply point against the minimum technical levels described in the NRS 048 document.

It does require that electrical utilities and end-users continuously monitor the quality of electricity acquired, consumed, distributed and in some cases, improvement on PQ.

By continuously monitoring PQ it is possible to mitigate concerns and assess the performance of those mitigation solutions. Innovative technological solutions for end-users exists to condition the voltage quality at the end-user if the electrical utility fails to deliver voltage at the minimum technical level. The gains in business and operational risk manifests in improved sustainability of the end-user (or utility) due to improved profitability and growth.

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5. AUTHOR

Principal Author:

Tanya van Zyl is the Quality Assurance Manager at the NCPC-SA. Having joined the NCPC-SA in 2016 she had been active in the quality assurance of the training offered, as well as assessment reports delivered by the NCPC-SA.

She studied Chemical Engineering at the North-West University in Potchefstroom. Tanya is a United Nations Industrial Development Organisation (UNIDO) qualified Steam Systems Optimisation (SSO) expert and trainer as well as Energy Management System (EnMS) Implementation expert, Resource Efficient and Cleaner Production (RECP) expert and Biogas project development expert.

Tanya's work experience includes 16 years in the energy, resource efficiency and renewable fields. This experience spans across sectors such as the industrial, mining, manufacturing, power generation, paper and pulp, chemical, commercial buildings, and public sectors. Her skills include Energy Management, Measurement and Verification, Project Management, Project Development, Business development, Quality Assurance, Sustainable Finance, Green Chemistry and Power Quality.

Tanya led the implementation of the Green Chemistry project in South Africa and was a speaker at the American Chemical Society's 24th annual Green Chemistry and Engineering Conference in 2020. She is currently focussed on development of new courses for the NCPC-SA with a strong focus on sustainability and energy.

Presenter:

The paper is presented by Tanya van Zyl.

INDUSTRIAL MOTORS IN THE INDUSTRY 4.0 ENVIRONMENT

Energy in the Industrial Environment and Industry 4.0 (IIoT)

Johan van Niekerk
Zest WEG Group South Africa

INTRODUCTION

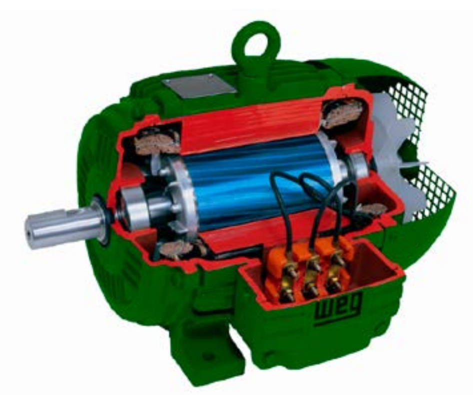
It may seem that the big, old fashioned "clunky" electric motor has little part in the scheme of things when related to IIoT and Industry 4.0. In this paper and presentation, we will show that the electric motor can contribute very significantly to sustainability through IIoT application. It is however not the standard electric motor on it's own that will bring this about. It is the electric motor used in conjunction with monitoring and communicating technologies. The use and control of electric motors is very significant for three reasons:

- Electric motors are the single biggest load or power consumer on the national grid.
- Using Industry 4.0 technology can significantly improve their performance and power consumption.
- Virtually all production is dependent on electrical motors. This includes anything from agriculture to poultry, cement, cars, petrol, food, beer, gold, diamonds, bread, etc.

If we utilise Industry 4.0 capabilities, we improve production (reduce cost) and reduce electrical power consumption.

MAIN

To start we must establish some definitions. There are many different types of electric motor. The most common electric motor and the one that contributes most significantly to energy consumption or more plainly "National Power Usage" is the asynchronous cage induction motor. These motors are available in 3 phase and single phase and are also known as a squirrel cage induction motor. In this paper and presentation all reference to electric motors means a squirrel cage induction motor unless stipulated otherwise. This is a perhaps a less technical terminology referring to it's construction. The induction motor has a stator connected to the electrical supply which induces an electric current and magnetic field in the rotor. The interaction of the stator and rotor magnetic field causes the motor to turn. It is asynchronous because the rotor rotates slower than the magnetic field in the stator. The squirrel cage naming is due to the rotor having rotor bars connected to an end ring which makes the rotor look like a squirrel cage. This is probably an American terminology that in South Africa may be better described as a "hamster wheel".



Standard AC Motor - asynchronous cage induction motor

The motor's shaft is coupled to a load which in turn rotates and produces mechanical work. Some examples would be: a pool pump, ore crusher, mill, conveyor, pump, fan and many other industrial loads. The basic technology of electric motors has not changed much. It was first patented by Nicholas Tesla in 1888 and designed and produced for practical usage in 1891 by General Electric. In 1896 an agreement between General Electric and Westinghouse produced the design that would be called the squirrel cage motor. The basic concept has not changed. Materials, manufacturing and design have improved. Modern motors are about 10% the size of the earliest motors. Electric motors frame sizes were standardised in the 1960s. As a result motor power ratings, frame sizes and other data have remained largely the same from 1960 to 2020. Since 1960, the motor has improved in terms of performance, current, torque, mechanical rigidity, and perhaps most significantly efficiency. At present there are technologies available to allow much higher power to be produced by a much smaller motor. The ruling efficiency standards as defined by IEC can also be significantly superseded. These technologies are not yet at a level suitable for practical mass production and common industrial usage. The benefits detailed in this paper reference standard "off the shelf" electric motors. These have efficiency defined in improving levels starting at IE1 (lowest) and rising to IE5. At this time the highest efficiency that is practical for general and mass industry usage is IE4. This has nothing to do with Industry 4.0 or I4.0, the similarity in nomenclature is pure coincidence.

IE1	IE2	IE3	IE4	IE5
Standard Efficiency	High Efficiency	Premium Efficiency	Super Premium Efficiency	Ultra Premium Efficiency

IEC Motor efficiency levels

The real Industry 4.0 advances in terms of electric motors lie in the ability to measure motor variables, communicate the data, analyse the data and then the understanding and control measures that follow as a result.

Let us first understand how IIoT and Industry 4.0 fit together. In modern times, starting in the late 1700s we had the 1st Industrial Revolution being the move from exclusive manual production to mechanised production using steam and water. This was followed by the 2nd Industrial Revolution in the late 1800s and early 1900s, marked by three main changes: electricity, rail and telegraph. This was when the modern production lines started, the most famous of the time being that of Henry Ford. The 3rd Industrial Revolution, also known as the digital revolution began in the 1970s and is the time where automation and computerised control became possible. The 4th Industrial Revolution terminology was first used in 2015. It is a more nebulous concept than the previous industrial revolutions and includes the following:

- Rapid and vast development of automation and interconnectivity.
- Massive data transfer, storage and analysis capability.
- Automation using data exchange between machines,

factories, regions and management across the globe.
- Adapting and improving the controlled process often without human intervention.

Motor Scan sensor

I4.0 then is the trend towards automation and data exchange which includes the use of computing and automation technologies such as Artificial Intelligence, Augmented Reality, Big Data, Cloud Computing and others using connectivity from the Internet of Things. Much of the communication, analysis and automation is autonomous of human intervention.

To quote Klaus Schwab, founder and executive chairman of the World Economic Forum who popularised the term: "The Fourth Industrial Revolution creates a world in which virtual and physical systems of manufacturing cooperate with each other in a flexible way at the global level". According to some we are already in the 5th revolution.

The 4th Industrial Revolution (4th IR or 4IR) includes the Internet of Things (IoT) which in turn includes the Industrial Internet of Things (IIoT). It is also called Industry 4.0 or I4.0 and builds on the previous revolution's automation capability with massively increased communication, data processing and computing capability.

It is the opinion of this author that there is a lot of hype around I4.0 that far exceeds its practical reality but that at the same time there is a lot of very real beneficial capability that is underutilised. The analysis, adaptation, improved control and autonomous actions of I4.0 technology is birthed in human design and intelligence developing and testing the I4.0 technology. It does not develop on its own. There are adaptive algorithms that can "learn" and adapt but these algorithms are also the product of human design. Once the design and testing are done though the flow of information and rapid analysis with corresponding control changes are truly astounding. Consider here that most of us have a smallish smartphone in our pockets with easily 10,000 times the memory of the desktop computers we used when we started our working careers. Applying this to the scale of industrial data, communication and computing may give an idea of I4.0 capabilities. The volume of data that must be transferred was not possible until recently when intercontinental and national fibre and radio links made it possible.

Those who have worked with electrical motors will know that they definitely cannot be sent into nor retrieved from the cloud! What has become possible is the measurement of key information which is then recorded, analysed, stored, retrieved and communicated. Due to I4.0 techniques the measurement is much quicker and the availability and analysis of the measured data much quicker and more user friendly. In I4.0 terminology: a sensor mounted on the motor or in proximity to the motor will communicate relevant motor data to a local real time control such as a mini-PLC or similar motor controller. Certain control adjustments will be done at local level, e.g., opening a valve to allow increased product flow. The local real time control or motor sensor will communicate to an "Edge Gateway", this allows the motor data to be sent via the Internet to the Cloud, where it is stored, analysed and adaptive responses implemented. For example, based on environmental data from Europe a textile manufacturing machine in Mauritius may increase output or even change product from one material to another due to weather changes in Eastern Europe. Alternatively, a defined maintenance schedule may be delayed due to reduced product requirement, this in turn would result in less wear and tear. As a result, normal scheduled maintenance and the resulting costs may be deferred.

Let's consider a real-world example comparing IR3.0 and IR4.0. A chemical factory in South Africa has 2000 electric motors used to drive the production process. It would be normal practice to have a preventative maintenance program to prevent unplanned outages due to failures.

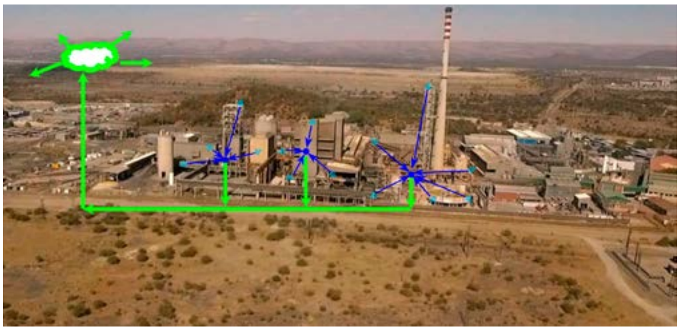
The IR3.0 method:
As part of this a technician would go around the factory and measure vibration and temperature on the electrical motors. He would use hand held, battery powered instruments. The measurement process would take two days. Many motors would be inaccessible or not running or not under load conditions rendering those measurements useless. After measuring about 20 motors the technician would have to download the data to a computer, put the instruments onto re-charge for some hours and then continue. At the end of the measurement cycle the downloaded data would have to be converted from "measurement instrument" format to analysis format such as possibly a spreadsheet.

As data built up it would have to be saved to "stiffies" as it would quickly become too much to be stored on a normal office computer. To get a wholistic picture, additional data such as: number of starts and stops, environmental data and production data would have to be obtained and collated. Important data such as power consumption and current drawn would be virtually impossible to obtain. Obtaining all the possible data by measurement, thereafter downloading, converting, collating and analysing it would involve days of work. Thereafter the technician or perhaps his supervisor would analyse hundreds of pages of data and report via email, written or verbal report to the plant engineer who in turn would report to the plant manager. Based on the reports, interventions could be planned and implemented. Some critical motors would have extremely expensive and complex permanently installed monitoring instruments. The cost and complication meant that only a very small number of motors would be thus monitored. This entire process would be subject to production variables, environmental variables and human error such as not holding the instrument probe correctly. It would also take a lot of time and therefore not allow for a critical analysis of second and third level data.

The IR4.0 method:
Relatively inexpensive sensors would be mounted on all the motors that should be monitored. Accessibility or

hazardous areas would not limit the sensor's use. They can be installed where no technician would ever have access! These sensors would have long life batteries or a power supply enabling them to monitor the motor 24/7/365. Most of the relevant information such as number of starts, running hours, temperature, vibration could be measured. From the sensor it would be sent via Bluetooth to a gateway and from there via the internet to a cloud-based system. A similar system would provide environmental and production data. The information would be constant, real-time information. Based on this many corrective actions could be implemented automatically at a local machine level. For example, a crusher motor may reach an alarm level temperature and the conveyor feeding it would be automatically slowed down to reduce load while an alarm is flagged for a technician to check the crusher.

Any number of constantly available reports could be accessed, hourly, daily, weekly or monthly as may be required. These would not provide hundreds of pages of data but would provide completed analysis. This would enable the engineering staff to make informed decisions at almost all times.



Motor Scan sensors throughout a plant and connecting to the cloud

Even better, many control improvements could be implemented automatically without the need for any reporting or human analysis. Taken a step further, similar information from similar factories across the world could be compared, analysing product tons vs electrical consumption, production loss due to defined failures, product quality vs process conditions, man hours vs tonnage, etc. Improvements in Mozambique could be rolled out in Mexico.

The possibilities for improvement are obvious. Many of the diagnostic capabilities are based on truly massive amounts of data and very specialised insight, however once the analytical model is established virtually anyone can access highly specialised analysis at the push of a button.

The speed, comprehensive nature and ready availability of data and analysis is a very large multiple of what could be achieved during I4.0.

Motor Scan sensor – data collection via Bluetooth gateway or by personal device

We may also consider this in a very South African context: constraints on electrical power available in the national grid. Information from Eskom and other research has shown that electrical motors are responsible for around 40% of national power consumption. If I4.0 technology and techniques can be used to improve on that 40% it can obviously have a significant positive impact. We believe that it is not only possible but also relatively easy. We will give some ideas and examples following. In a recent study by energy specialist Dr Theo Covary of Unlimited Energy concluded that South Africa could save 474GWh per annum in South Africa by using premium efficiency motors alone. The study was funded by the European Union (EU) and endorsed by the National Regulator for Compulsory Specifications (NRCS) and the Department of Trade Industry and Competition (DTIC). This is a benefit as a basis or "entry level" precursor to the fuller I4.0 possibilities. Consider the following as being the practical possibility from an electrical motor perspective:

- Implement a national Minimum Energy Performance standard (MEPS) similar to other industrialised nations.
- Use motor monitoring sensors with cloud based analytical software to monitor all motors essential to production or energy saving.
- Implement the maintenance and process actions as indicated by the software.

At this stage one can almost hear the reader cry out "what about costs??" in indignation! The reality is that I4.0 use in terms of motors does not have to be costly and in fact will save much more than the usage costs. In the foregoing example a technician would be occupied for days obtaining data which an engineer would take hours to analise. Thereafter some possible improvements or interventions could be implemented. Nowadays the data collection and analysis are almost entirely automated and virtually instantaneous. The result is that many more improvements can be implemented and much quicker. The result should be improved productivity, i.e., more products for the same hours and electrical energy (kWh) or alternatively less hours and kWh for the same products. Either way a given production output will use less electrical energy. The second aspect would be reduced failures due to better prediction and therefore preventative maintenance. Done correctly, using higher efficiency motors and I4.0 based analytical control will reduce production costs and electrical power consumption.

Amongst the electric motor variables that may readily be measured and analysed on-line using I4.0 technology are:

- Number of starts
- Operating hours
- Motor vibration
- External vibration
- Motor temperature
- Ambient temperature
- Motor power
- Motor energy consumption
- Motor speed
- Driven load vibration
- Driven load temperature
- Bearing defect frequencies both motor and driven equipment

Based on this, problems like misalignment or unbalance or high load can be diagnosed and potential failures averted.

We will consider some further, real-life scenarios. Note that the examples use real case study information but that end user information has been changed due to publication approval being time consuming and difficult to obtain.

A company with several sugar mills spread throughout sub-Saharan Africa found that during 2021 their output reduced by 4.9% without being directly attributed to stoppages, failures or raw sugar cane quality. They found that sugar crystallisation time was taking 6% longer due to increased ambient temperature. This possibly being from either global warming or El Nino effects. The same was not true of their European counterparts. They adapted their production planning to process the sugar at a cooler time of day and achieved a 4.2% improvement. I.e. the 4.8% reduction was eliminated and 4.2% additional production was gained.

A 355kW motor on a ventilation fan had suffered several catastrophic bearing failures resulting in substantial downtime, production loss and unplanned maintenance costs. On the second failure the motor was sent for analysis and no cause of failure could be established. When re-installed the alignment was done with great care and record kept thereof, however, within a month a 3rd failure was experienced. Thereafter, I4.0 on-line monitoring was used. Within the first hour a load unbalance on the fan was diagnosed. The fan which is in an enclosed duct was opened and the blades found to have an accumulation of dirt that resulted in an unbalance. Once cleaned the problem has not recurred.

A 5MW slipring mill motor at a mine that is many days travel from any main centre experienced repeated flash-overs across the sliprings. Each time this happened there were several hours downtime due to having to isolate, clean and repair. Many possible causes and corresponding fixes were postulated, however none led to a lasting solution. Again, using I4.0 technology the motor and particularly the slipring compartment were monitored. Within a week of installation, it was found that the ambient temperature was higher than specified and also the motor was running at 12% higher load than specified. Both the ambient and the load were within the motor capability but the brushes used were selected for an operating temperature 20˚C below the actual temperature. Once the brushes were changed to the correct grade there was never again a flash.

CONCLUSION

At this stage of technology development, not using the benefits of I4.0 to improve electric motor power consumption and reliability may be compared to not using a smartphone. At the same time, I4.0 is not a "silver bullet" that will allow factories and mines to run themselves and no longer require technicians or engineers. Rather the combination of qualified staff intelligently applying technology will result in a lower power consumption and improved productivity.

Author:

Johan van Niekerk was born and has lived his life in the industrial hub of South Africa, our dearest Gauteng. Love it or hate it, Gauteng and it's industry is very much a part of what makes South Africa run.

Johan started work by doing an electrical apprenticeship at the old AECI, home of the former "dynamite factory". From there he worked his way through college. While at AECI he was involved in and became responsible for modernisation of parts of the 4 ammonia plant through the use of what was relatively new technology at the time – variable speed drives and also PLC automation. This led to Johan being employed by ABB Drives in various roles during the next 7 years. It was a time when automation technology, mainly PLCs and their larger brothers, DCSs were developing very rapidly. The range of technologies and their application at AECI was very instructional.

Shortly thereafter Johan moved to Zest, now Zest WEG to start-up the VSD business for them. This has been a very successful venture. He was very fortunate to be there and involved during a period of great development both of variable speed drive and motor technology. Electric motors developed through 4 efficiency levels while drives not only increased in efficiency but became IIoT capable. At present Johan is responsible for the motors, drives and switchgear within Zest WEG in South Africa. He has a wealth of practical, "real world" knowledge and experience.

RENEWABLE BIOGAS BOILER CO-FIRING FROM WASTE WATER AT NIGERIAN BREWERIES

Dr. D. Johnson, Umxhumanisi Engineering South Africa
Emeka Odogwu, Nigerian Breweries, Nigeria.
Email: djohnsoster@gmail.com
Emeka Odogwu, Nigerian Breweries, Nigeria. Email: chukwuemeka.odogwu@heineken.com

Abstract

This paper describes biogas co-firing from waste water treatment plant at Nigerian breweries.

Nigeria has an installed electricity generation capacity of 10396 MW, and 6056 MW available [1]. Many industries are reliant on their own diesel- or natural gas based off-grid generators. The brewing industry consumes large quantities of non-renewable gaseous- or liquid fuels for generating the heat required in the beer-making process.

Waste water produced by the breweries are high in useful COD (Chemical Oxygen Demand) and other pollutants, and is processed before being discharged into the environment. The waste water is treated in a biological water treatment plant, including an anaerobic digester, where methanogenic organisms convert the nutrients to biogas.

The biogas is utilized to co-fire a boiler, or a dedicated biogas boiler, which provides about 10% of the total energy requirement of a brewery.

1. INTRODUCTION

Nigeria is a vast country with an installed electricity generation capacity of 10396 MW, and available capacity of 6056 MW [1]. This is low for a country with more than 170 million people and an economy of more than 300 billion dollars GDP. Many industries are reliant on their own diesel- or natural gas based generators. Consequently, the Nigerian brewing industry consumes large quantities of non-renewable gaseous- or liquid fuels for running boilers in the beer-making process.

Waste water is produced in the brew house, cleaning processes and in the packaging halls. The water produced by the breweries are high in useful COD [Chemical Oxygen Demand] and other pollutants, and is processed, to regulatory standards, before being discharged into the environment. .

The waste water is passed through a sedimentation pit and course- and fine screens, where after the different effluents are mixed in an equalization tank. The different waste water streams have different pH levels (waste water from the brew house has a relatively lower pH while waste water from the packaging halls has a relatively higher pH). Mechanical mixing and natural acidification, by micro-organisms action, reduces the pH for the next step in the waste water treatment process.

The water then moves into an anaerobic digester where methanogenic micro-organisms converts the nutrients to biogas. The remaining nutrients are digested in an aerobic digester, where after the cleaned water is returned to the water bodies. The sludge is either d-watered first or removed by tanker and disposed off as a valuable agricultural fertilizer to the local agriculture.

The anaerobic digester produces useful amounts of biogas, which is used to co-fire one of the boilers, or a dedicated biogas boiler, and potentially providing about 10% of the total energy requirement of the brewery. Because methane is a known greenhouse gas, about 25 times worse than carbon dioxide [4], the biogas is flared during boiler down time, or partially, if the biogas generation is in excess of the boiler requirement.

The biogas reuse, from the waste water treatment plant, reduces the non-renewable use of fuel, the energy cost and the environmental impact of breweries.

2. BIOGAS GENERATION

Shown in Fig. 1 below, there is an outline of the waste water treatment process and is briefly described here.

The water received from production first passes through a sedimentation tank where undissolved solids are settled. After settling, the water passes through a coarse screen, to remove large objects, followed by a fine screen to remove fines such as small plastics, bottle crown, bottle caps, and spent grains.

The water then enters into an acidification tank, where acidogenic- and acetogenic micro-organisms, collectively known as acetogens, converts some of the COD into Acetic Acid [2]. At breweries, the water entering the acidification tank is predominantly basic, i.e. has a high pH. While the acidification tank's pH is kept below 8.5, the acid forming micro-organisms work symbiotically and drops the water's pH.

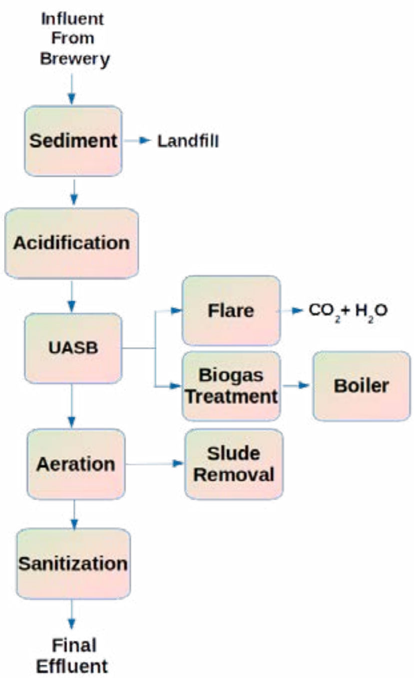


Figure 1. Waste Water Treatment Process

If needed, the water's pH is corrected to between 6.7 to 7.2, before it's fed into the UASB (Up-flow Anaerobic Sludge Blanket) reactor Figure 2 [2][3]. Water is fed into- and recirculated in the UASB for about 24 hours, where the bulk of the nutrients are consumed and biogas is produced. The acid forming micro-organisms continues to convert the COD into VFA (acetic acid) inside the UASB.

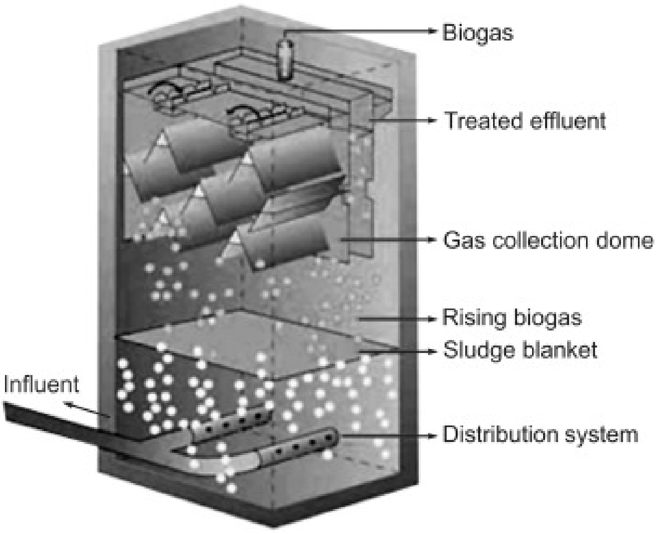


Figure 2: UASB operation [3]

Anaerobic methanogens converts the VFA into biogas, consisting of CO^2 (Carbon Dioxide), H_2S (Hydrogen Sulphide) and CH_4(Methane). The remaining nutrients are digested in an aerobic digester by aerobic micro-organisms. The biologically cleaned water is then processed further by sanitizing, filtration, Reverse-osmosis etc, before being discharged or re-used.

The aerobic sludge can be either dewatered, or removed by tank truck, and is a valuable agricultural fertilizer.

3. BIOGAS TREATMENT

The biogas consists mainly of CH_4, H_2S and CO^2. When conditions are optimal in the UASB, the bulk of the biogas captured is Methane. For re-use of the biogas, some processing is required to make it suitable for use as fuel in a standard boiler by a biogas scrubber.

Figure 3: Biogas Scrubber

The biogas scrubber (Fig,3), that removes the, H_2S is a vessel that uses aerobic micro-organisms for clean-up. Generally the H_2S fraction is reduced to less than 500 ppm.

Figure 4: Biogas flare and drier

The water vapour is condensed out by a cooling unit (Fig. 4), before it is being sent to the boiler. When the boiler is not consuming biogas, or too much is produced, the biogas is flared (Fig, 4), because the greenhouse effect of Methane is more than twenty five times [3] than that of carbon dioxide .

4. BOILER CO-FIRING

The biogas volumes produced in brewery waste water treatment plants is not sufficient to fire a standard brewery package boiler, so usually a second injector is fitted to one of the boilers for co-firing [5]. An example of a duel fuel burner arrangement is shown in Fig. 5.

Alternatively, a purpose built biogas boiler is used in addition to the installed boilers.

Figure 5 : Dual Gas Burner on Boiler

Shown in Table 1 below, are the biogas consumption of an example Nigerian Breweries plant.

Table 1: Example Plant Biogas Consumption September 2022

Day	1	2	3	4	5	6	7
Production	2748	2576	2564	2543	2601	2237	2319
Consumed	2482	1952	2499	2383	2559	2194	2267
Utilized	90%	76%	97%	94%	98%	98%	98%
hr/d	22,73	18,29	24	23,13	24	23,99	23,99
% CH_4	0,85	0,85	0,85	0,85	0,85	0,85	0,85
GJ/day	84,4	66,4	85	81	87	74,6	77,1

The biogas produced, from the waste water, reduces the fossil fuel requirement for steam production.

5. CONCLUSION

Treating brewery waste water is a legal requirement by environmental agencies worldwide. Brewery waste water lends itself well to anaerobic treatment, which produces useful quantities of biogas. The biogas is treated and re-used as fuel to co-fire boilers or fire a biogas boiler.

Biogas, produced from Brewery Wastewater is carbon neutral. The Carbon emissions is countered by the growing of more grain, which absorbs CO^2 and is converted into starches and sugars by the plants.

The grains are then used for brewing more malt products and the waste is converted to usable thermal process energy again.

Using biogas to partially replace fossil fuels, reduces the net GHG (greenhouse gas) emissions of Nigerian Breweries.

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Principal author:

Dr David Johnson holds a Ph.D. and Masters degrees in Electrical Engineering from the University of Cape Town and B.Eng in Mechanical Engineering from the University of Stellenbosch. He is currently employed with Umxhumanisi Engineering, South Africa. His interests are energy efficiency, alternative energy, alternative mining methods and energy storage.

Co-author:

Emeka Odogwu holds a B.Eng in Mechanical Engineering from the Federal University of Technology Owerri. He is currently employed with Nigerian Breweries PLC, Nigeria. His interests are energy efficiency, renewable energy, maintenance, brewing processes.

A REVIEW OF QUANTIFICATION OF ENERGY SAVINGS UNCERTAINTY: WITH FOCUS ON UNCERTAINTY BUDGETING AND MEASUREMENT CALIBRATION REQUIREMENTS

Dr Mark Rawlins,
Pr Eng, CEM, CMVP
Energy and Combustion Services (Pty) Ltd.

ABSTRACT

Dealing with uncertainty in M&V-based energy savings assessments encompass a field of expertise with a vast domain of knowledge – with many physical measurement, statistical, and mathematical foundations. This paper highlights two important aspects of energy savings uncertainty quantification, namely: budgeting for uncertainty and practical risk mitigation for uncalibrated measurements.

Note: This paper addresses the subject matter in a semi-formal manner, to create awareness and highlight specific aspects in a simplified way. The idea is to provide insight rather than strict mathematical and statistical analysis. So, all technical details must be confirmed before applying the methods discussed here.

1. INTRODUCTION

It is impossible to measure and apply physical quantities without errors. Further, the final desired result of the energy measurements is generally not equal to the directly measured quantities. Rather, results are derived from some functional relation between the measured quantities and the results. By example, electrical energy is derived from summation over time of the product of current and voltage. With each having its estimated value and random error with these errors propagating through a functional relationship.

In the M&V process of savings determination, there is the increased complexity due to counterfactual energy estimation – savings cannot be measured because the energy was not used. Rather, they must be predicted using a baseline functional model to estimate the energy in the absence of the savings (the counterfactual). These models and savings algorithms introduce further error and uncertainty in the results.

Establishing the combined uncertainty with all these measurements and predictions can be difficult and encompasses numerous fields of expertise; underpinned by a vast domain of knowledge with deep physics, statistical, and mathematical foundations. M&V uncertainty quantification is further compounded by the fact that energy engineers are generally not statistics or metrology professionals.

However, despite difficulty in execution, quantification of uncertainty is highly recommended for M&V and generally a requirement for energy efficiency incentive/programme assessments. And there is much documented support for this activity – with several guidelines that contain methods for uncertainty quantification such as, SANAS TG 50-02 [1], [2], and [3]. These provide insights with acceptance levels/tests and have proven practical use.

There are two aspects of the uncertainty in M&V that are worthwhile discussing on their own: uncertainty budgeting and verification of uncalibrated measurements. In the overall process, these are shown as *1 and *2 in Figure 1 – which is the typical pattern of activities for M&V savings assessments.

2. SAVINGS ESTIMATION: AN OVERVIEW

Ultimately energy savings determination can simply be stated as:

$$E_s = E_{ab} - E_{ap} \quad \text{(Eq 1)}$$

Where, E_s is the energy savings, E_{ab} is the adjusted baseline energy, and E_{ap} is the assessment period energy consumption [4]. Noting that one must also state the uncertainty in E_s.

E_s cannot be measured, because E_{ab} needs to be determined using a baseline functional model. Also noting, the baseline period energy has no application in the savings assessment – it is only used to determine the functional relationship between work done and energy consumed. In the process to finally get to using Eq 1, as shown in Figure 1, there are many areas of uncertainty in measurement and calculation that need to be accounted for. Some of these are highlighted in the sections that follow.

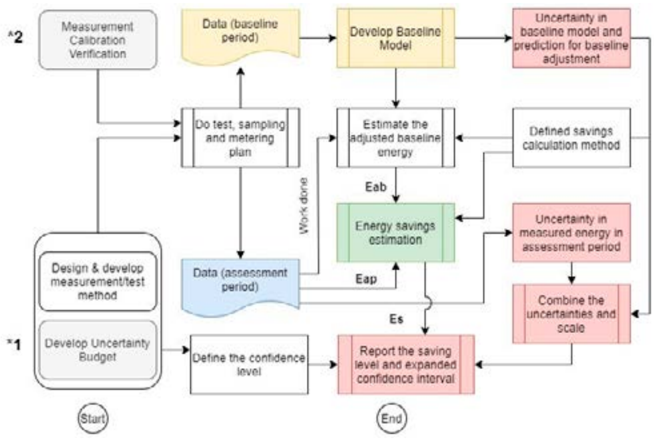

Figure 1: Calculation Flow: Uncertainty in Energy Savings

3. UNCERTAINTY BUDGET

There is much discussion amongst M&V practitioners and related stakeholders around the cost of M&V inspections – where these costs are driven by and related to the acceptable degree of uncertainty in the statement of savings. A key understanding is that it takes more effort and cost for reducing uncertainty and increasing accuracy and precision. However, during M&V inspection planning, a comprehensive uncertainty budget is seldom calculated, assessed, and documented – together with the key stakeholders seldom specifying uncertainty expectations. Uncertainty is typically dealt with after the savings quantification - it is what it is after the fact.

A notable exception to this is the definition and calcula-

tion mechanics of the savings quantification method to be applied – which encompasses the inspection option, such as, retrofit isolation or whole facility [4] and, in instances where the savings effect is a relatively small proportion to the overall energy consumption say <5%, design of experiments such as randomised control trials with test and control subjects and encompassing methods such as Difference in Differences (DID) [5] and [6].

Generally, selecting the correct savings calculation method has the highest impact on savings quantification and uncertainty – specifically enabling the M&V process to reliably detect a saving when an energy saving has occurred.

3.1 Budget: What is an uncertainty budget?

An uncertainty budget is a ranked table of components that contribute to uncertainty in the energy savings assessment – revealing the identity, quantity, and character of each source of uncertainty. It is an indispensable method for M&V with the goal of effectively supporting management of uncertainty using an organised and structured approach.

3.2 Components: What are the components of an uncertainty budget?

An uncertainty budget can be simplified or extensive and there are guidelines on the required components of uncertainty – for example SANS 50010 [4].

The author's recommendation, for simplified uncertainty quantification and assessment that is alignment with the energy savings calculation, is that the following components of Table 1 are included in the uncertainty budget - not ranked: (a), (b), (h), (j), (k), (m), (n), (p). Some of these are discussed briefly in the sections that follow.

Uncertainty component (b):
When one is dealing with quantification of uncertainty – these uncertainties need to be combined using acceptable methods – requiring that each are of the same physical units either as a standard deviation, standard error, or relative uncertainty scale. A common mistake is to attempt simply to sum uncertainties in different physical units.

Table 1 : Components of uncertainty

SANS 50010:2018 Section 7 [4]	
(a)	M&V method chosen
(b)	calculation method chosen
(c)	M&V boundaries chosen
(d)	selection or choice of significant energy consumption within the boundary
(e)	selection or choice of energy governing factors
(f)	frequency of data collection
(g)	data intervals
(h)	measurement method(s) used
(i)	competency of the M&V practitioner
(j)	sample size and whether the sample size is considered representative
(k)	measurement equipment uncertainty
(l)	possible consequential effects not included in the M&V result
(m)	the baseline period energy consumption
(n)	the assessment period energy consumption
(o)	an estimation of interactive effects
(p)	model diagnostics and bias

Different units of measure can be combined so long as the result of their combination is in units of energy. As an example, energy (Wh = 3600 Joule) can be calculated from the product of current (A), voltage (V), and time in hours (h). Taking energy $E=A\times V\times h$, then the uncertainty in the calculated energy is the propagation of uncertainty from the individual components expressed as:

$$\left(\frac{u(E)}{E}\right)^2 = \left[\left(\frac{u(A)}{A}\right)^2 + \left(\frac{u(V)}{V}\right)^2 + \left(\frac{u(h)}{h}\right)^2\right]$$

Where the form $\frac{u(x)}{x}$ the relative uncertainty and these are combined in quadrature (the squared exponent).

Therefore, it is not helpful to simply add the uncertainties in A, V, and h to express the uncertainty in energy consumption - such as: $u(A)+u(V)+u(h)$ - because the units of measure are incompatible, and this is incorrect functional propagation of uncertainties.

Regarding (Eq-1), the savings equation, subtraction of assessment period energy E_{ap} from the adjusted baseline energy E_{ap} results in a combined uncertainty expressed as:

$$u^2(E_s) = u^2(E_{ab}) + u^2(E_{ap})$$

Where in the form $u^2(x)$ the $u(x)$ can be in the absolute units of energy (Joule, Wh) or the combined standard errors or the relative precision of the energy measurements/calculations.

As a note, and in keeping demonstration of the methods simple, the above propagation of uncertainties is only statistically valid if the variables are uncorrelated. Excellent references explaining deeper technical detail on uncertainty propagation are [7] and [8].

Monte Carlo Methods:
Further, there are Monte Carlo methods in the M&V uncertainty framework that are practical alternatives to the analytical propagation of uncertainty using the above methods – see [9] for a formal overview of the Monte Carlo Method. Further, SANAS TG 50-02 Appendix A Section 3 [1] demonstrates how this method is applied. The method is often used when selecting M&V option "Calibrated Simulation" and when the effect or saving size is small (<5%) – this is because the method provides improved credible intervals for the statement of uncertainty.

Uncertainty components (j), (m), and (p):
Fundamentally in M&V, the baseline energy profile needs to be adjusted to the assessment period work done conditions – requiring a functional energy model relating the energy governing factors to the energy consumption. Energy modelling can be a tricky affair with many traps awaiting the inexperienced. However, there are several references providing guidance on regression models for M&V practitioners - see [1], [2], [10], and [11].

Model predictive performance: The predictive performance of the baseline model constitutes a significant proportion of the uncertainty budget (often more than 60%) – so special attention must be paid to verifying the model predictive capability. Therefore, uncertainty assessment in M&V, as a minimum, one must quantitatively assess model predictive performance. Clear guidance on this is provided in [1].

There is no guarantee that this mathematical model can learn from the data to enable fidelity in representation of the physical system being modelled – see Appendix A. However, M&V experience has demonstrated the unreasonable effectiveness of even simple regression models for energy prediction.

Also, guidance can be found in [1] providing specific acceptance levels on maximum total model uncertainty. For example, when stated as a coefficient of variation of root mean squared error CV(RMSE) [1] [2] – these guidelines indicate CV(RMSE) levels between 20% and 30%.

Data size: Regarding the data requirements, there are basically two aspects of sample size that need to be considered. Is there sufficient data to detect a saving within the uncertainty of the measurements (the data needed to reliably detect the effect or saving size) and to build an acceptable predictive baseline model? Essentially, as the effect size decreases, the number of samples required increases. That is, more data generally equates to higher precision – see [12] for an overview of accuracy versus precision.

Data sampling size is foundational to good M&V, and acceptable practice should be applied. In this regard, 3 sample size estimation procedures are highlighted.

Simple method: Firstly, a simple approach can be applied that focuses on the ratio of the sample data variability to the expected relative precision or effect size [13]:

$$n_s = \frac{z^2 \times cv^2}{e^2}$$

Where, z is the z distribution score [14] defined by the selected uncertainty level, cv is the expected coefficient of variation as a fraction [13], and e is the desired relative precision or effect size as a fraction – see Appendix B for how this equation is derived.

Note that this method can result in small sample size recommendations – so take care in its application.

Statistical Power method: Secondly, and a more complex method, one can increase the sample size to increase the probability of finding an energy saving when an energy saving is present – which is basically increasing the inferential power of a test [15]. Statistical power of a test has four related parts: effect size, sample size, uncertainty level (or significance), and hypothesis testing [24].

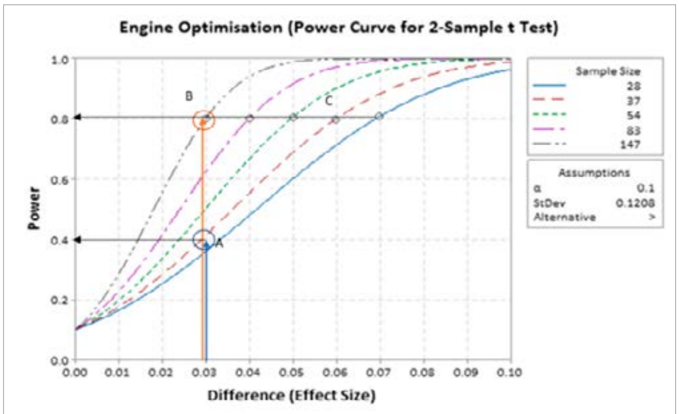

Figure 2: Statistical Power Curves

The more statistical power the better. It is common practice for the author to set a statistical power of 0.8 (80%) for M&V inspections.

Again, avoiding diving here into the statistical complexities, the following demonstrates the principle of the sensitivity of sample size needed for the effect size detection. Looking at Figure 2, taken from an M&V project dealing with diesel engine energy optimisation, where the expected effect size is 0.03 (or 3%).

For a statistical power level of 0.4 (point A), one would need 37 samples. For the same effect size of 0.03, to obtain a power level of 0.8 (point B) one would need 147 samples. Doubling the effect size to 0.06 (or 6%), one could achieve a power of 0.8 (point C) with 37 samples.

Note the non-linear relationship between effect size and sample size for a desired statistical power.

Rule of thumb: Lehr's rule of thumb [15] says that the sample size for a Two-sample t-test with power 80% and significance level a=0.05 should be:

$n = 16\frac{s^2}{d^2}$, where s is the estimate of the standard deviation and $d=\mu_1-\mu_2$ the to-be-detected difference in the mean values of both samples (for example, adjusted baseline energy and assessment period energy respectively).

There are software packages and libraries that are good for this work, for example, G*Power [16] and a Python-based introduction for statistical power [17].

Regression sample size: For regression modelling there is an approximate rule that relates the number of parameters or energy governing factors in the model to the power of test. Using the relationship between the F-test [18] and the expected adjusted coefficient of determination $R^2_{adjusted}$ [19], for each possible model size, statistical power of the test between 80% and 90%, and two-sided confidence level of 90% or level of significance (a = 0.05) – then the recommended sample size is given in Table 2 [1].

Table 2: Sample size for number of regression parameters

PN (Number of regression parameters – excluding the constant)	N(PN) (Recommended sample size given the number of regression parameters)
1-3	40
4-6	45
7-8	50
9-11	55

This sample size recommendation here is a grey area for uncertainty in M&V, because there are many M&V assessments that use 12 samples (say 12 months of the year) which could be considered statistically indefensible unless the effect or savings size is large; say >10%.

3.3. Uncertainty quantification – workflows and time

It is important to note that uncertainty quantification takes time, and this needs to be planned for. This is especially important with complex energy processes and small effect sizes.

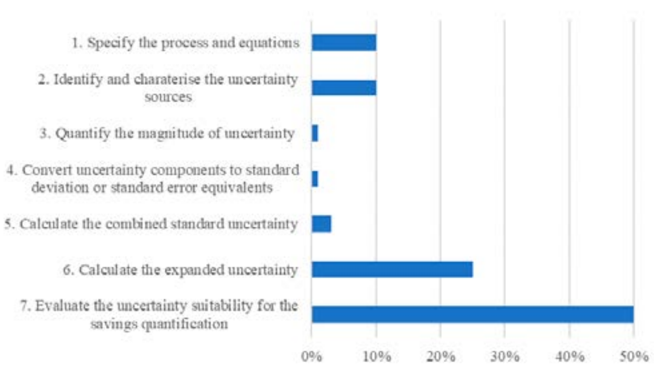

Figure 3: Uncertainty Time Allocation [20]

Dealing with uncertainty typically encompasses 7 workflows – shown here in Figure 3 together with an approximate indication of the relative time allocation for uncertainty quantification and assessment [20].

Approximately 25% to 35% of the M&V time budget is spent on uncertainty quantification and developing the M&V measurement plan. One then needs to include time for this effort during development of the M&V plan.

4. UNCALIBRATED METERING VERIFICATION

M&V faces a constant challenge in obtaining measurements from calibrated meters. Many internal production process meters, energy meters, and meters used as proxies for energy metering are found to lack traceability to a calibration standard or have self- or manufacturer-developed in-situ calibration, but this can be proprietary to specific operations and not traceable to a standard.

There are conservative approaches in M&V that insist on calibrated and traceable metering as the only acceptable sources of data. So then, why not simply calibrate the meters and get on with the work? The problem is that many meters cannot be calibrated in-situ, or cannot be removed for calibration, or calibration is prohibitively costly. This can mean the death of the M&V process for energy savings assessments. However, one can be practical about this and apply engineering, physics, and statistics to justify and support the use of the meters when verified but not calibrated.

With reference to SANAS TG 55-01: Section 5: Verification when Calibration Certificates Are Not Available [21] – deals with practical scenarios where calibration is difficult, exorbitantly expensive, not possible, or calibration certificates are not available and yet a project must be measured and verified. Further, with reference to SANS 50010 [4] – Section 6.3 highlights calibration requirements – and this should be read in conjunction with Section 7.4 Note 5 for uncalibrated measurements.

4.1. Two-metering point principle

Key to verifying an uncalibrated measurement is being able to compare the energy, or volume, or mass flow from two independent measurements. That is, one needs at least two metering points for the same energy or material flow. Ideally, one of the measurements is used as a reference and is based on a calibrated meter or industry recognised, approved, and verified measurement system.

4.2. Application examples

Examples of actual application types are shown in Figure 4 (A to D). For each, P1 is the reference metering point, and P2 is the metering point that needs to be verified.

Example (A): mining haul truck fuel consumption:
This is an energy verification example. Here, there are individual sub-meters (P2) that record the fuel issued to the trucks. These volume flow meters are not calibrated but carry manufacturers certificates of accuracy. The main meter (P1) is calibrated, and all the fuel flow through this meter has been transferred to the trucks via the sub-meters. The statistical task is to verify the fuel volume issued by the sub-meters P2 using P1 as reference.

Example (B): mining haul truck tonnage hauled:
This is a production mass verification example. Here, there are weighing systems (P2) on the trucks that measure the net mass (payload) on the truck. These truck payload systems are periodically tested for serviceability. The surveyors account for the mass balance of material handled (P1) using industry standard methods and calibrated equipment. The statistical task is to verify the total mass measured by the truck systems (P1) using the survey values (P1) as reference.

Example (C): solid fuel supply to a steam boiler:
This is an energy verification example. Here, a steam boiler has a feeder that has a dynamic scale (P2) on the fuel feed conveyor between the coal bunker and boiler. This scale is periodically serviced but not calibrated to a traceable standard. This scale records the fuel mass flow to the boiler – thereby enabling boiler efficiency determination across the range of steam production rates. The fuel comes onto the site via a calibrated weighbridge (P1) as bulk and is discharged into the coal bunker. The statistical task is to verify the conveyor scale measurements (P2) using the weighbridge scale measurements (P1) as reference. Noting there are some other practical considerations. One needs to ensure that the total consumption in the aggregated periods significantly exceeds the bunker stock capacity. Otherwise, corrections need to be made for period bunker opening and closing stock values for each period. Therefore, data aggregation periods less than weekly/monthly are typically not suitable for this application.

Example (D): paper production metering:
This is a production mass verification example. Here, the production product mass and area are measured with several uncalibrated production meters (P2). Using acceptable accounting procedures and weighbridges for material mass balance, the virtual reference meter (P1) for raw stock, waste, and finished production can be used to verify the production meters (P2).

5. STATISTICAL PROCEDURES

Once there is a defined system in place for measurement and aggregation of data for P1 and P2, one can apply certain statistical procedures to verify P2.

5.1 Statistical equivalence principle

The principle of equivalence testing is that one is trying to determine equivalence of two measurement sets within a practical margin (M) and not whether they are different. So, one needs first to assume that the measurements are different (the null hypothesis) and then test to prove that they are equivalent (the alternative hypothesis).

Two methods will be explained here, with examples. These are the Paired T-test for Equivalence [22] and Orthogonal Regression aka Deming Regression [23]. Typical of statistical-based inferencing, there are several rigorous mathematical and statistical rules and conditions with these tests – but here, we will keep things simplified for demonstration of the methods. For further background on this, the following references can provide deeper insight: [24], [25].

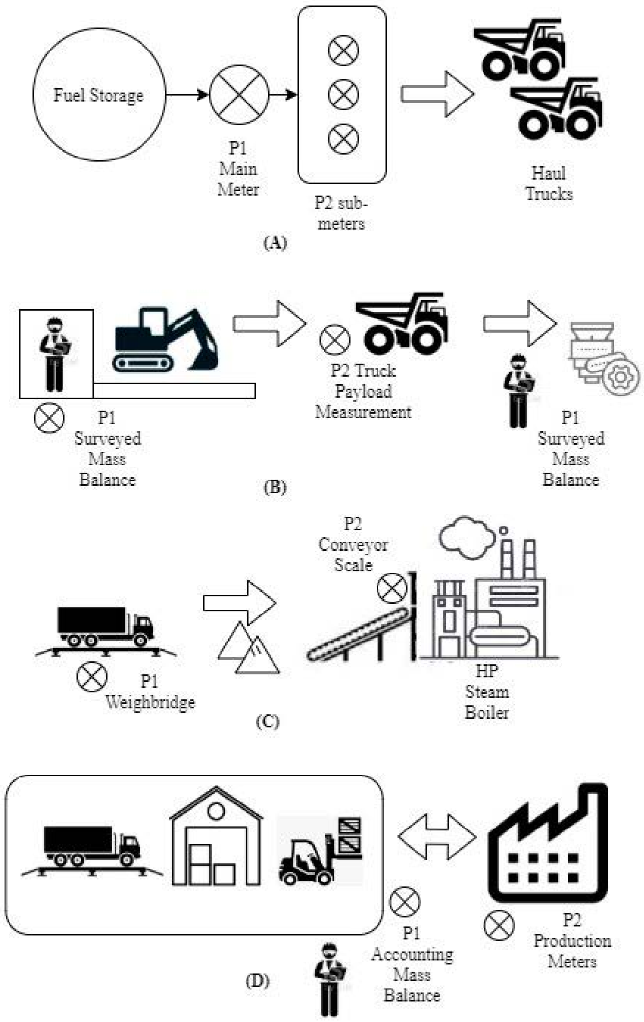

Figure 4: Examples of metering verification

5.2. Paired T-test for equivalence

The test for equivalence can be done by taking the continuous random variable X_{P1} for the aggregated measurements taken for metering point P1 as compared to a second paired random variable X_{P2} for the aggregated measurements for metering point P2.

These are paired in the sense that the totals for each metering point are n paired observations (X_{P1w}, X_{P2w}), w=1,2,...,n weeks (but could be days or months). The differences for each pair of observations are formed as $D_w = X_{P1w} - X_{P2w}$.

Now, if μ_D represents the mean of the differences between the two variables, M to represent the so-called zone of equivalence, and LCL *and* UCL the lower and upper confidence levels respectively of the mean difference μ_D, then the null H_0 and alternative hypothesis H_1 are:

$$H_0: LCL < -M \text{ or } M < UCL$$

$$H_1: -M < LCL \text{ or } UCL < M$$

The LCL and UCL can be estimated by using the Standard Deviation $S_{\mu D}$ of the mean of the differences and the number of differences n to calculate the Standard Error $SE_{\mu D}$ of the mean of the differences:

$$SE_{\mu_D} = \frac{S_{\mu_D}}{\sqrt{n}}$$

Then, together with looking up the $T_{df(1-\alpha)}$ value of the Student's t-distribution with $df=n-1$ degrees of freedom and the confidence level $1-\alpha$ that would have been selected earlier in the uncertainty budgeting process (for example 0.8 or 80%). Then the LCL and UCL can be defined as:

$$LCL = \mu_D - T_{df(1-\alpha)} \times SE_{\mu D}$$

$$UCL = \mu_D + T_{df(1-\alpha)} \times SE_{\mu D}$$

This is shown graphically in Figure 5.

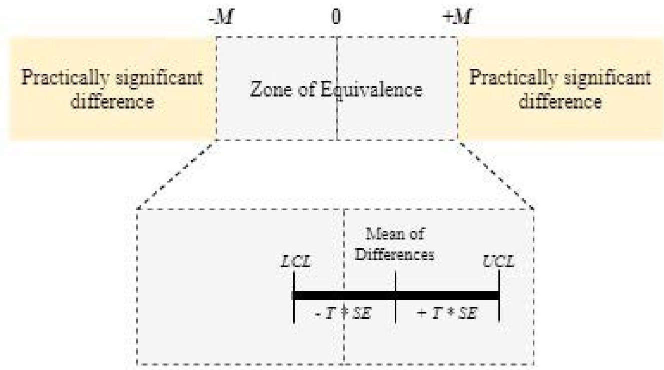

Figure 5: Examples of metering verification

Regarding the zone of equivalence, defined by -M to +M, there is no statistician who can help the M&V Inspector define these limits – because it is not a question of statistics – rather, it is a question of what size difference produces tangible impacts on the assessment of the energy savings. Within the uncertainty budgeting process, one sets this zone, typically as a percentage of the average measured value of P1 (the reference measurements).

5.2.1. Example of paired T-test for equivalence

Take the following Table 3 and 4 of paired values for P1 and P2 and do the equivalence test – with the test results shown in Table 5 and 6:

Table 3: Data for demonstration of paired t-test for equivalence

w	1	2	3	4	5	6	7	8	9
P1	57	63	66	74	77	77	78	79	80
P2	53	69	63	76	75	79	77	77	81

Method:
Test mean = mean of P2
Reference mean = mean of P1
Lower equivalence limit = -0.05 × mean of P1 = -3.6167
Upper equivalence limit = 0.05 × mean of P1 = 3.6167

Table 4: Descriptive statistics of P1 and P2

Measurement	N	Mean	StDev	SE Mean
P2	9	72.222	9.0523	3.0174
P1	9	72.333	8.2462	2.7487

Table 5 : Equivalent test results

Null hypothesis:	Difference ≤ -3.6167 or Difference ≥ 3.6167		
Alternative hypothesis:	-3.6167 < Difference < 3.6167		
α level:	0.05		
Null Hypothesis	**DF**	**T-Value**	**P-Value**
Difference ≤ -3.6167	8	3.3490	0.005
Difference ≥ 3.6167	8	-3.5613	0.004

Table 6: Equivalence test CI and Acceptance Interval

Mean of Differences	StDev	SE	95% CI for Equivalence (LCL, UCL)	Equivalence Interval (-M , +M)
-0.111	3.14024	1.0467	(-2.05759, 1.83536)	(-3.61667, 3.61667)

The LCL and UCL are within the equivalence interval (or zone of equivalence), Therefore one can claim equivalence. This is supported by the two P-values being not greater than 0.05 the α level selected – see Figure 6 for a graphical representation of this fact. The mean difference confidence interval is within the upper and lower equivalence limits. Therefore, measurements from P2 are equivalent to P1.

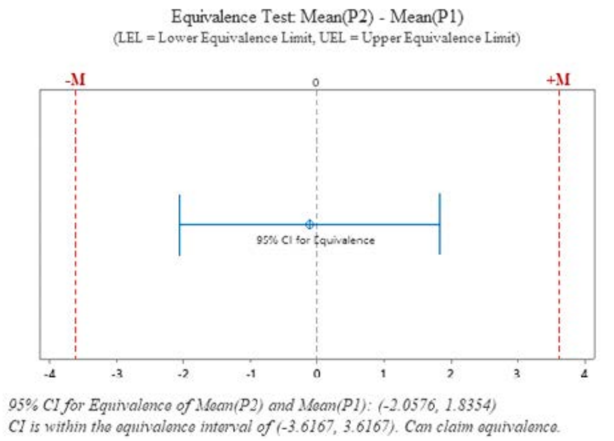

Figure 6: Graphical example of Paired T-test for Equivalence

5.3. Orthogonal Regression (Deming Regression)

Orthogonal regression, also known as "Deming regression" [23], examines the linear relationship between two continuous variables. It is often used to test whether two instruments/meters or methods are measuring the same thing – with a good use case within M&V for verifying measurement P2 to P1 as the reference.

Unlike simple linear regression (ordinary least squares regression - OLS), both the response (measurement P2) and predictor (measurement P1) in orthogonal regression contain measurement error. Whereas in OLS, the predictor variable is assumed to be free of error.

The regression equation takes on the form of OLS:

$$\widehat{P_2} = \beta_0 + \beta_1 P_1$$

Where, β_1 is the intercept or constant value and β_2 is the regression slope value. The test for equivalence using this regression approach is to calculate and test the approximate confidence intervals for β1 being $CI_{\beta 1}$ and for β_2 being $CI_{\beta 2}$. As for the Paired T-test equivalence test the same a level and degrees of freedom are used. There are two tests performed with the following criteria:

Test 1: $\beta_0 - \frac{CI\beta_0}{2} < 0 < \beta_0 + \frac{CI\beta_0}{2}$, which means that the confidence interval for the intercept must contain 0 to accept this first part of the equivalence test.

Test 2: $\beta_2 - \frac{CI\beta_2}{2} < 1 < \beta_2 + \frac{CI\beta_2}{2}$, which means that the confidence interval for the slope must contain 1 to accept this second part of the equivalence test.

This can be demonstrated using the data of Table 3 – producing the regression fitting results as shown in Table 7 and Figure 7.

Table 7: Orthogonal regression results

Predictor	Coef	SE Coef	Z	P	Approx 95% CI
Constant	-7.941	11.254	-0.705	0.480	(-30.0, 14.1)
P1	1.108	0.154	7.159	0.000	(0.8, 1.41)

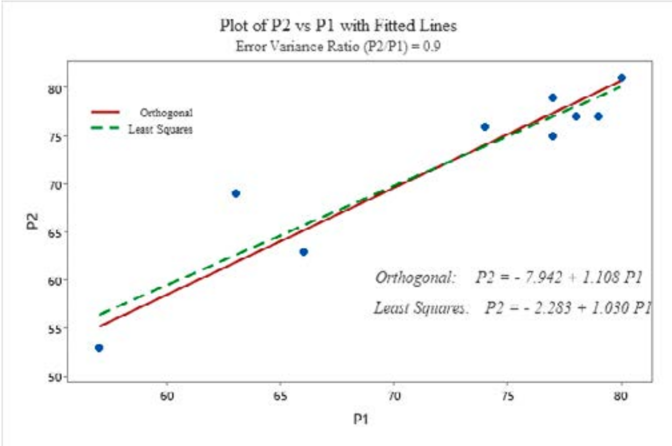

Figure 7: Graphical example of Paired T-test for Equivalence

Equivalence test results are then checked against the test criteria. With reference to Table 7, these checks are:

Test 1: The confidence interval for the coefficient of the intercept or constant contains 0, and Test 2: The confidence interval for the coefficient of the slope contains 1. Therefore, using P1 as the reference measurement point, it can be concluded that P2 has the equivalent measurements as P1 – that is, equivalence is verified.

6. CONCLUDING REMARKS

Correct handling of uncertainty in M&V savings assessments has importance in terms of credible M&V statements on assessed savings.

In this paper, it is recommended that the M&V practitioner develops an uncertainty budget prior to assessing the savings, and preferably includes this budget in the M&V plan. Even though uncertainty budgeting and quantification is a significant proportion of time for credible savings assessments, much benefit can be achieved from this in terms of clearly understanding the critical areas requiring attention and how much time, effort, and cost this attention will require. Highlighted here, two critical areas driving uncertainty are how much data is needed to develop a baseline energy model and increase the power of detecting a saving when a saving has been achieved.

The issue of how to practically handle uncalibrated me-

tering has been addressed with typical application examples and statistical procedures – hopefully to avoid situations of disqualification of savings determination due to not knowing whether meters are measuring the correct quantities. It is recommended that uncalibrated metering be used only as a last resort and the recommendations of SANAS TG 55-02 [1] and SANS 50010 [4] be understood together with applying practical engineering sensibility on the issue. One should be fine if defendable procedures/methods are documented together with the test results and assumptions made.

AUTHOR

Dr Mark Rawlins is the Chairperson and Chief Engineer of Energy and Combustion Services (ECS).

He is a registered Professional Engineer, CEM, CMVP, and SANAS-Accredited Technical Signatory for M&V. Mark has 35 years of experience in Energy Management, energy efficiency, engineering and energy systems design, manufacturing plant and mining operations, and energy/operations performance verification. He has specialist expertise operations research and process modelling, statistics/machine learning, measurement, and data/information systems. A core competency being energy modelling and simulation for complex processes.

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Appendix A – Learning from data

The M&V savings estimation is deeply linked to learning from data with all its complexities, and there are many areas with uncertainty in learning from data.

Looking at Figure A1, in the process of baseline modelling, one is attempting to obtain an approximate mathematical function g(x) that simulates the real function or unknown target function f(x). However, in the M&V framework, one will never know exactly what f(x) is. The issue one then faces is testing whether g(x)≈f(x) – does the model suitably approximate the real system. Noting that g(x) can take on many forms (suitable candidates) that are highly dependent on the training data and the learning algorithm A. An excellent foundational reference is [26].

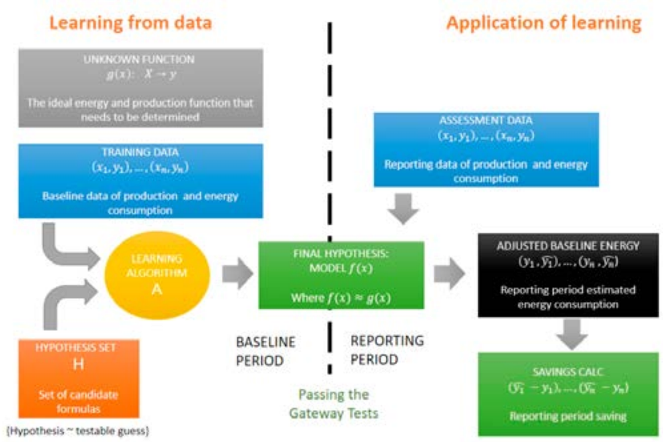


Figure A1: Learning from Data

Key elements in developing this model of the energy system are: whether the data for training truthfully represent the energy system; selection of the learning algorithm; and the execution of several tests for the model performance on "unseen' data that is not in the training data.

Handling of these issues are adequately described in SANAS TG 50-02 [1].

As a takeaway, even simple regression models have proven effectiveness in M&V – even across different energy systems and production settings. The author's opinion on this is that, once you have correctly defined the energy governing factors using appropriate boundaries for the energy and workflows, energy and associated work done with the energy are typically highly correlated and the energy system can often be described via engineering and physics principles that can be used to cross validate the proposed models.

Appendix B – Sample size estimation

The sample size can be roughly estimated by defining:

Relative Precision [13]: $e = z \times \frac{SE_y}{\bar{y}}$ or $e = t \times \frac{SE_y}{\bar{y}}$

Standard Error: $SE_y = \frac{S_y}{\sqrt{n}}$

Coefficient of Variation: $cv_y = \frac{S_y}{\bar{y}}$

Then, by substitution: $e = \frac{z \times cv_y}{\sqrt{n}}$

Giving sample size: $n = \frac{z^2 \times cv_y^2}{e^2}$

Further details are documented in Uncertainty Assessment for IPMVP – Chapter 1.5 [13].

Note: if the data is yet to be collected, one needs to make an estimate of the coefficient of variation. In [13], there is a method shown that enables recalculation of the required sample size – once the variation in the data is known.

LIGHT HAS BECOME THE NEW COMMUNICATION LANGUAGE IN IoT

Simon Poo (Specification Specialist)
Signify South Africa
Woodmead North Office Park, 54 Maxwell Drive, 2191
South Africa

ABSTRACT

The spectrum where we communicate wirelessly using different technologies is getting congested, there is no room for growth, no more room to accommodate more devices or no more room to increase the bandwidth and the world currently facing the bandwidth problem. Communicating using light will be useful for many applications, for instance in office, industry, or hospitality, because light bandwidth is much bigger to accommodate more devices.

The number of connected devices is increasing massively.

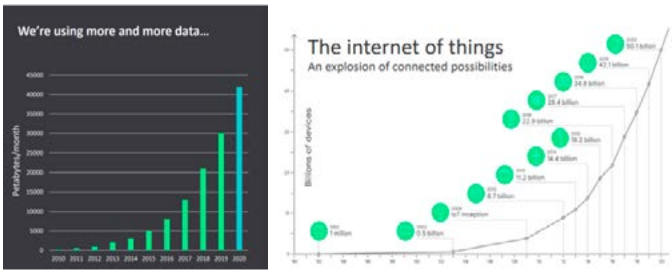


Figure 1

It is the world as we all know it by now: worldwide, internet data traffic is doubling every 18 months and much, if not most of this data at some point passes through a wireless network.

There is growing concern on using radio frequency to communicate wirelessly. The spectrum does not provide enough room to grow.

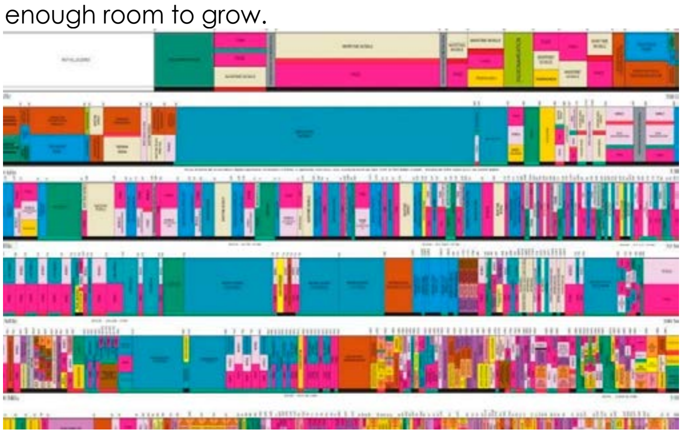


Figure 2

Bandwidth Crunch – means the spectrum where we communicate wirelessly using different technologies is getting congested, there is no more room to grow, no more room to accommodate more devices or no more room to increase the bandwidth. And if we look to each single bandwidth on **figure #2**, it is occupied by technology or by a protocol and cannot enlarge it or grow it anymore. This is the problem the world is facing now, the **bandwidth problem**.

Lighting can be the solution to this radio waves bandwidth problem.

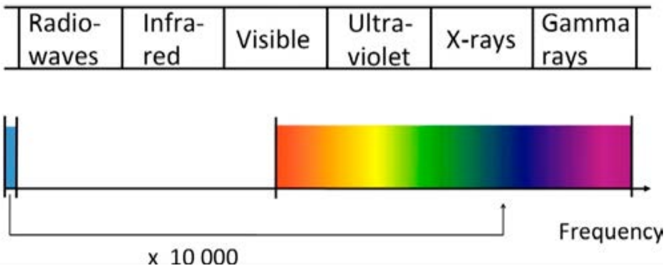


Figure 3

The lighting can help, because the concept of using the light to communicate is not NEW, we already know the optical fibres, the backbone of the internet, even the remote control at home you transmit a very low bit rate over infrared connection or both lighting spectrum. So, the idea of using light to communicate is not new, it existed for so long. But how we bring it into the IT infrastructure and into the lighting infrastructure, this is the innovation we bring by **Li-Fi (Light Fidelity)**. **Li-Fi** is a two way high speed wireless communication like **Wi-Fi** but using light waves instead of radio waves to transmit data.

Theoretically the bandwidth of lighting is much bigger than the bandwidth of the whole radio spectrum (it is 1000 bigger). Here we are not comparing to a single technology. We are comparing the whole radio spectrum. You can imagine 1000 bigger, so capacity to accommodate more devices is much bigger. If we are talking about IoT and the connected devices over internet.

The capacity for light bandwidth is enormous and it is free to use, and it does not need a license, if we look to the radio wave or the radio spectrum. If the country wants to launch 4G or 5G, it is a complex very expensive process to get a license to agree with the government and so on. Lighting is free of charge and you do not need to pay for the license and the infrastructure is everywhere.

Does the world need LI-FI? The answer is YES.

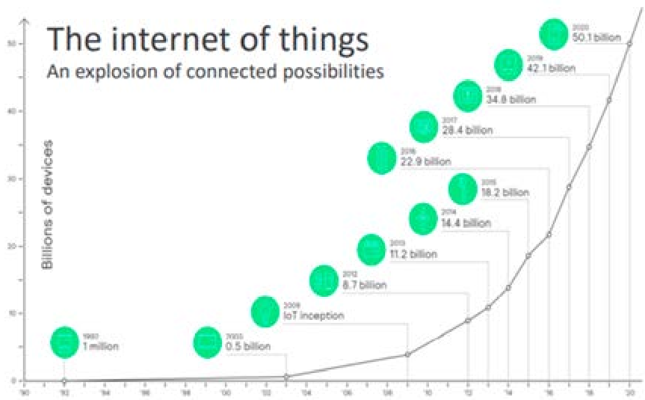


Figure 4

Why? Because of 2 reasons:

1. On the figure above (**Fig. #4**), we see the digitalization – any device now can connect to the internet.

The assumption now is in the next 3 years each person will have 20 devices connected to the internet. Your personal devices i.e., laptops, cell phone, consumer devices (coffee machines etc.). We can see from **figure #4**, we are reaching 50 billion devices connected to the internet and the number is expected to grow at a higher rate, we are looking at the industrial segment, all these connected machines etc. The number is increasing rapidly. At the end of the day, all these devices need to consume data and to transfer information. And the current platform to do that is not enough. Example: when you are at the airport, a very crowded place trying to connect to **Wi-Fi (Wireless Fidelity)**, a lot of people around you are using their own devices and in the end you have a sluggish network, or the connection is always disrupted, or you don't have enough bandwidth to do what you want to do.

The is the first concern, the number of connections is increasing massively.

2. **The second aspect is not only about the quantity of those devices, but also about the quality of data consumed by those devices**. In the consumer domain, if you look at your TV, we are talking about standard definition (SD), we are talking about high definition (HD). The quality of this information is growing rapidly (at an exponential growth rate). And the amount of consumed data is doubled. And by the end of the day again the resources or the platform we have, does not grow or does not move forward.

   And this is what the telecom industry calls bandwidth crunch.

Benefits of using Li-Fi:

1. Security – We communicate wirelessly using radio technology. So, the information is in the air- you cannot control it and to whom it reaches, (although it is encrypted and put through a lot of security protocols). By the end of the day, a matter of cracking the encryption depends on time and resources. But theoretically, any encryption can be cracked and can be hacked. There is a feeling in some entities or some government institutions like military, or even some application in the office, - they are not confident of having all this information outside of the building, in the air and the possibility is there that anybody can crack it. Or at least they can distort or jam this information.

   Using Li-Fi, light does not penetrate through walls and windows. It will be confined inside the room or inside the area where we are meant to have the communication. You need to be in the line of site to get the communication. Anybody outside the room or in another location will not see the signal, will not see what is communicated inside. It is really a secure communication.

2. Reliability and the stability of the communication – we agree that we communicate using light because the bandwidth is much bigger to accommodate more devices. The signal is stable, always reliable. Regardless of how many users are connected, regardless of information transferred using Li-Fi, it always provides reliable communication compared to Wi-Fi. It also does not interfere with other RF (Radio Frequency) resources. If you are standing next to the office building, you will find around 15 to 20 Wi-Fi networks. All these networks interfere with each other and these will affect the speed and the reliability once again. Li-Fi is providing a stable network compared to any other RF because it does not interfere with other devices (Interference free wireless communication).

3. Fast and reliable network access up to 200Mbps

Figure 5

A Sustainable Alternative to Cellular Radio Masts

Cellular radio masts consume a lot of energy and most of the energy is not used to transmit the radio waves, it is used to cool the radio masts. Then the efficiency of such radio mast is only at about five percent and that creates a big problem.

Li-Fi has a low energy consumption because it can be incorporated in energy efficient LED lighting technology. Using the visible light frequency spectrum instead of the RF (Radio frequency) provides a sustainable alternative to achieve high-speed wireless connectivity. **Professor Harald Hass** explains that many cellular radio masts, especially in developing countries, still rely on diesel fuel and the power grid. As a result, cellular radio masts are a major contributor to the total mobile power consumption. TechRadar reports that "cellular radio masts account for almost 60% of total mobile network power consumption while 20% is consumed by mobile switching equipment and around 15% by the core infrastructure." But the new technology will not replace traditional RF-based technologies entirely and will instead, work alongside it to mitigate energy consumption".

Contact person: Simon Poo
e-mail: simon.poo@signify.com
Cell: +2771 674 9602

STRUCTURAL ANALYSIS AND SEISMIC RISK FOR ALIWAL NORTH, SOUTH AFRICA, AND ITS SUITABILITY AS A GEOTHERMAL FIELD USING GEOPHYSICS

CJS Fourie[1], A Kijko[2], PL Roux[3], and D Johnson[4]*

[1]Walter Sisulu University, East London, Email: sfourie@wsu.ac.za and stoffel.aeon@gmail.com
[2]Natural Hazard Centre University of Pretoria, Pretoria, Email: andrzej.kijko@up.ac.za
[3]Pangaea Geophysics and Geodesy Working Group, Email: pierre.pggwg@gmail.com
[4]Mvelo Matla, Johannesburg, South Africa, South Africa, Email: djohnsoster@gmail.
*Corresponding Author

Abstract

The suitability of any specific area to be developed for geothermal energy depends, among others, on the geologic structure, which plays an important role in controlling the fluid flow within a geothermal system. A complex structural environment, such as intersecting dykes and faults, is an important aspect of how it controls geothermal fluid circulation.

Geophysics is an important tool for characterising the structural and stratigraphic settings in such areas. Apart from elevated temperatures, sufficient subsurface permeability is required to enable the extraction and/or circulation of the working fluids at the required flow rates for a sustained projected energy production over a prolonged period (30-year period). In most instances, it is necessary to increase the permeability in the subsurface rock volume through practices such as fluid pressurisation and hydrofracturing. However, such enhancement could lead to an increase in seismic activity.

In this study, we present the results of the geophysical analysis of the Aliwal North area in South Africa, which is considered to have geothermal energy potential. The analysis comprises qualitative geophysical interpretation (magnetic and satellite data) of the area, and delineate the surficial and subsurface geological structures that could control the permeability and geothermal fluid flow. We also conducted quantitative modelling and inversion of the magnetic data to verify the depth of the structure in the area along the faults and dykes. The spatial regional geothermal gradient data of the area were correlated with the Advanced Spaceborne Thermal Emission and Reflection (ASTER) surface temperature and surface emissivity data of the same area.

The seismic hazard and risk study completed for the study area yielded peak ground acceleration data and return periods for certain magnitudes of seismic events. The data indicate the base line seismicity of the area before the possible development for geothermal exploitation.

Keywords: Geothermal Potential; Regional Geophysics; Satellite Imagery; Seismic Hazard; Aliwal North

1. INTRODUCTION

Globally, approximately 44 TW of geothermal heat is transferred through convection to the surface. The largest portion of this heat (30 TW) is generated by radioactive decay in the core and mantle of the Earth. The difference (14 TW) indicates continuous cooling of the Earth, mainly through the oceans (Michaelides 2012). In specific geological areas that are currently active or have experienced tectonic activity in the past, superficial geothermal thermal energy occurs at the surface at higher temperatures where the energy is transported at much higher temperatures. This phenomenon occurs at Aliwal North in South Africa (Figure 1).

Depending on the natural geothermal gradient of a location, temperatures in the range 120–320°C are found in several countries worldwide at depths of 2 000–4 000 m. Any water in these geological strata attains the local temperature and, therefore, is an exploitable geothermal resource. In South Africa, because of the average geothermal gradient (Figure 2), only specific areas are suitable for geothermal development (Dhansay et al. 2014, 2017). At Aliwal North, the heat flow is estimated at 50 mWm^{-2} (Figure 2), with a geothermal temperature gradient of approximately 36°C/km (Dhansay et al. 2014, 2017). Accordingly, a temperature of 180°C at a depth of 5 km is sufficient to operate a binary cycle geothermal power plant. We interpreted regional airborne magnetics, Landsat 5, and Advanced Spaceborne Thermal Emission and Reflection (ASTER) data for the area.

The results indicated adequate geological structure to support the development of geothermal energy in the area, i.e., the structure supports sufficient permeability of the subsurface to enable extraction and/or circulation of the working fluids. Numerous dolerite structures are located in the area, of which a large ring dyke is the most prominent, and historic tectonic activity has probably led to the faulting. Modelling of the magnetic data showed the structure is deep enough to reach the Archaean basement to obtain elevated temperatures for a geothermal power plant if the optimum drilling positions were established.

At pristine geothermal energy fields, energy is extracted from shallow host rock with high temperatures to generate steam for electricity generation or district heating. In South Africa, locations that fit these criteria are not apparent. Exceptions for elevated heat flow from the mantle, as at Aliwal North, are located at current or ancient tectonic plate boundaries (Figure 1), such as orogenic belts that are more fractured due owing to the tectonic history.

According to Majer et al. (2007), problematic induced seismicity at several geothermal sites indicates a need to determine and mitigate any potential problems that such phenomena could cause for proposed geothermal projects. Therefore, we conducted a baseline study to evaluate the Aliwal North area for seismic hazard and risk to compare with future induced seismicity, should the geothermal field be developed and operated. In addition, determining the seismic hazard and risk characteristics could aid the design of the structure by estimating the peak ground accelerations (PGAs) for the area.

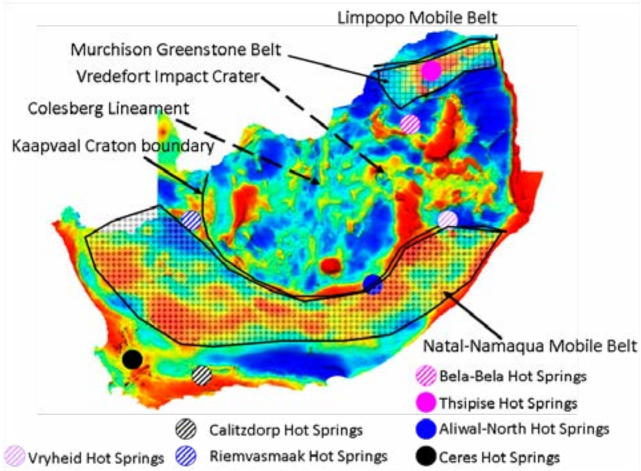


Figure 1: Current hot springs and larger target mobile belt regions indicated on the Regional Gravity Image of South Africa (Johnson and Fourie 2016).

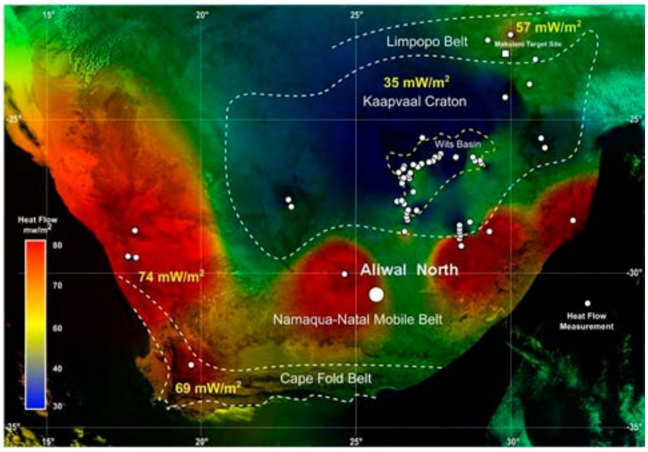


Figure 2: Geothermal energy potential of South Africa (Dhansay et al. 2014).

2. GEOTHERMAL SOURCES IN SOUTH AFRICA

South Africa has no active volcanoes but has several ancient plate boundaries (Figure 1), of which the Cape Fold Belt (500 Ma), and the Limpopo (2.7 Gy) and Namaqua–Natal (1.1 Gy) mobile belts are the most important. These ancient plate boundaries are not single lineaments but extend over larger areas that were formed by ancient continental collisions (Catuneanu et al. 1998, 2005).

During the breakup of the Gondwana supercontinent (180 Ma), rifting produced extensive lava flows (Drakensberg Group Lavas). The lava flowed through a network of pre-existing fractures known as the Karoo Dolerite Suite (Woodford and Chevallier 2002). Several ring dyke structures intruded as part of the Karoo Large Igneous Province (KLIP) intrusion (Figure 3).

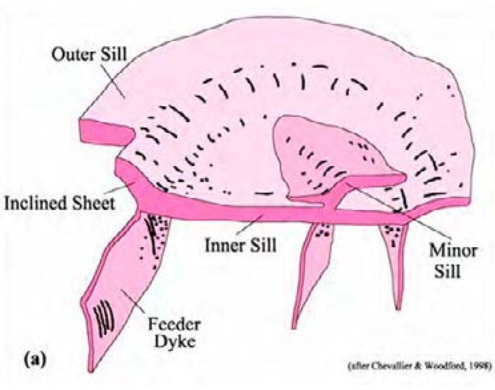


Figure 3: Karoo ring dyke schematic (Woodford and Chevallier 2002).

3. GEOLOGY OF THE ALIWAL NORTH AREA

The surface water temperature of the hot water springs at Aliwal North in the Molteno Formation of the Karoo Supergroup is 36°C throughout the year, with a temperature gradient of approximately 35°C/km (Dhansay et al. 2014, 2017). The Aliwal North hot springs are associated with fractures and fault zones related to the Namaqua–Natal Mobile Belt (Figure 1) and through the dolerite dykes (groundwater localisers) which intruded during the breakup of Gondwanaland at 180 Ma. Aliwal North is located in the Beaufort Group, Tarkastad Subgroup, and Stormberg Group of the Karoo Supergroup (Figures 4 and 5).

The Burgersdorp Formation is at the apex of the Beaufort Group, and the Molteno, Elliot and Clarens formations are in the Stormberg Group. The Drakensberg Group Basalts are at the apex of the Stormberg Group (Catuneanu et al. 2005). The geology map of the Aliwal North study area (Figure 4) is an excerpt of the regional 1:250 000-scale 3026 Aliwal North map. The map shows the stratigraphic distribution in the study area, and comprises four 1:50 000-scale topographic sheets (3026DA Aliwal North, 3026DB Bosberg, 3016DC Kramberg, and 3026DD Vineyard). Hobday (1973) emphasised that detailed geophysical investigations are crucial to understanding the thermal springs in the Karoo Supergroup, of which Aliwal North is an example. During the Triassic period (250 to 200 Ma), Karoo deposition of the upper Beaufort and Stormberg groups occurred and coal formed in the Stormberg Group.

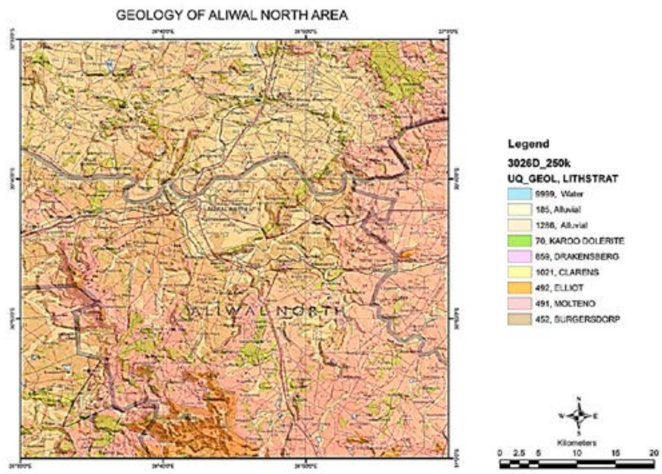


Figure 4: Geology map of the Aliwal North area (Council for Geoscience 2017).

The Southern Oil Exploration Corporation (SOEKOR) borehole WE 1/66 was drilled in 1966 in the Aliwal North District as part of the oil exploration programme during the previous century. The borehole was drilled to 3 692 m on the farm Weltevrede 117, Aliwal North. The borehole coordinates are 30.90S and 26.85E, and the collar elevation is 1 532 m (Linol et al. 2016). Drilling stopped at 3 692 m on encountering the Archaean basement granites. The borehole log (Figure 6) confirms the Karoo Supergroup stratigraphy, which are the Dwyka, Ecca, and Beaufort groups, together with the Adelaide and Tarkastad subgroups. The borehole intersects several dolerite sills at various depths through the succession. The thicknesses of the sills vary between 10 and 340 m, confirming the model of a network of dolerites that extends from the basement to the surface (the last sill is at the contact between the Karoo Supergroup and the Archaean basement granites).

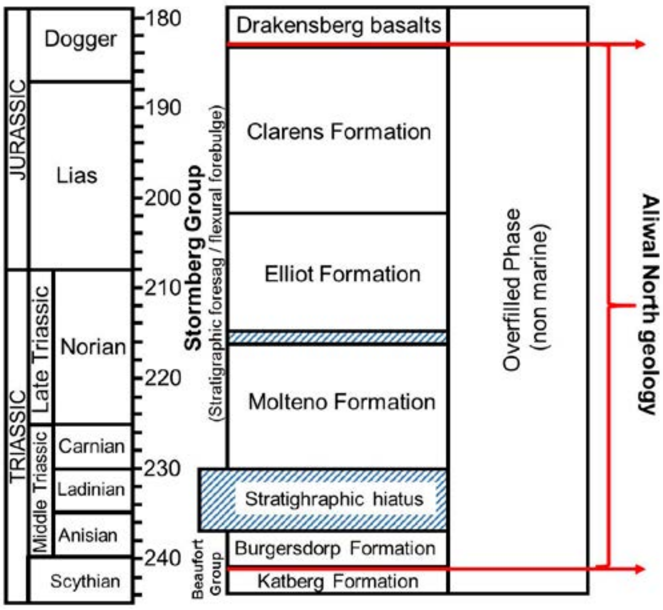


Figure 5: Stratigraphic column, with the major lithostratigraphic subdivisions of the Karoo Supergroup in the Karoo Basin in the Aliwal North region of South Africa (modified after Catuneanu, et al. 2005).

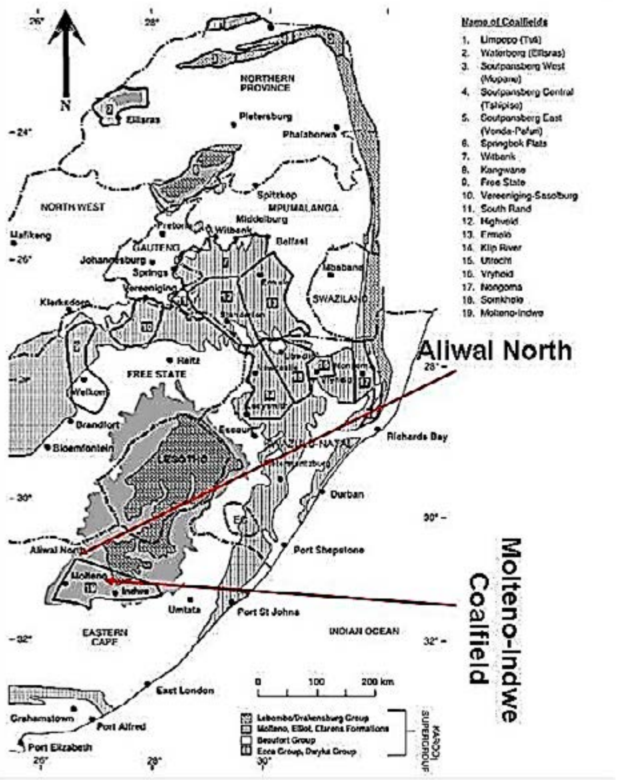


Figure 7: Coalfield distribution in South Africa, showing the Aliwal North area (modified after Jeffrey 2006).

Coal formed in the Burgersdorp Formation of the upper Beaufort Group and the Molteno, Elliot, and Clarens formations of the Stormberg Group that occur at Aliwal North. The coalfield (Figure 7), called the Molteno–Indwe Coalfield, is one of 19 coalfields identified in South Africa (Jeffrey 2006). The coal is an important clue to the origin of the methane gas in the Aliwal North hot springs water and in the marshes around the spring. A larger geothermal gradient is present in this instance because of the high methane content of 69% in the emerging water at Aliwal North, as organic material in rocks is converted to methane above 70˚C (Coleman et al. 1995). The coalfield contains faults and sills that cover 30% of the Molteno−Dordrecht−Indwe region, which is erosion resistant. The dykes (thickness up to 20 m) strike north–south and east–west, and dips are recorded to vertical to sub-vertical dykes (Jeffrey 2006).

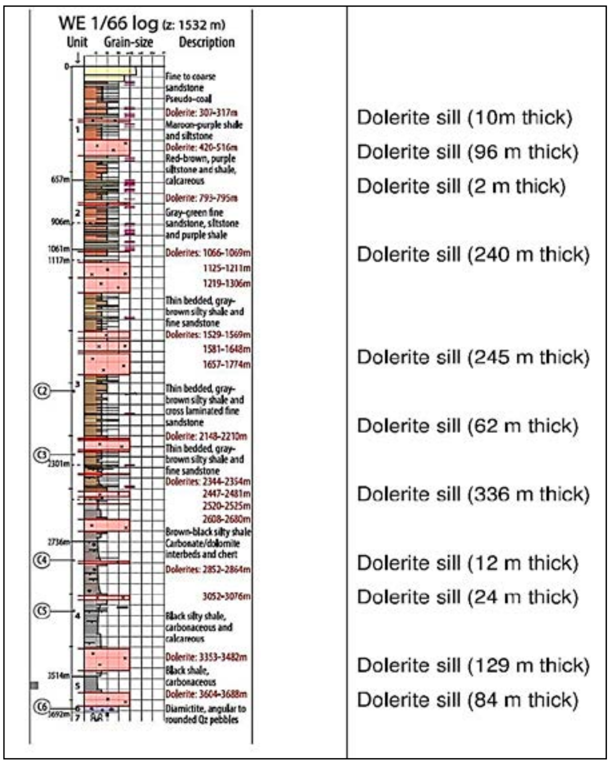


Figure 6: Log of the deep SOEKOR borehole WE 1/66, drilled in the Aliwal North area (modified after Linol et al. 2016).

Donald et al. (1992) suggested that most hot springs are linked with waning stages of volcanic activity. However, Aliwal North is situated on the roots of an ancient orogeny event (Namaqua–Natal Mobile Belt), and the heat source or flow path of the water causes deep-seated hot fluid to move through fractures in the rock. Owing to the tectonic history of the area, the rock is permeable and the structures are interconnected, allowing the flow of fluids that are replenished by the infiltration of surface water and rainwater (the Orange and Kraai rivers flow on several of these structures). The infiltrated water from the surface is heated by the rock that is closer to the mantle (geothermal gradient), with the resultant thermal water returning to the surface through the created fractures (permeability).

The explanation above represents only one possibility. Findings from the Kola Deep Drilling project on the Kola Plato in Russia offer a different view (Kremenetski and Ovchinnikov, 1986). The borehole (12 064 m deep) was classified into two sections. Section 1 is from 0–6 842 m and section 2 from 6 842–12 064 m, which consists of crustal materials, and the basement is Archaean granite-gneiss, which is similar in South Africa. Density zones, decreased by natural hydraulic fracturing from progressive metamorphism under closed system conditions were identified during the drilling project in the upper crust at a depth of 4 500–9 000 m. Prominent textural variations of rocks, with an increase in porosity, were found with the presence of mineralising fluids (water), which are specific features of these zones. A heat-production model was proposed for the Archaean crust. The crustal contribution to the heat flow is 25 mWm^{-2}, or 52% of the total heat flow, and that of the mantle is 22–24 mWm^{-2}, or 48% of the total flow (Kremenetski and Ovchinnikov, 1986).

4 MATERIAL AND METHODS

4.1 Geophysical Interpretation of Regional Data

Several geophysical techniques, e.g., the magnetic method, were employed at Aliwal North to investigate

the structure for permeability of the subsurface. As geothermal energy originates from larger depths, the focus was on techniques that facilitate surficial and deep-level investigations (Kana et al., 2015). The obvious target areas could be superficial indications of geothermal activity such as hot springs. In this study, we focussed on geophysical and spaceborne techniques suitable for comparing and investigating geological structures that could control permeability and geothermal fluid flow. In addition, we determined the seismic hazard and risk to evaluate the baseline to compare with future increased seismicity, if the geothermal field were developed. The techniques we employed are the:

- Magnetic method;
- Landsat 5 imagery;
- ASTER imagery;
- Seismicity and;
- Geothermal gradient data.

4.2 Magnetic Method

During tectonic processes (e.g., subduction and orogeny), the geological materials are exposed to severe pressures and temperature, possibly leading to fracturing, thinning, and thickening of the crust, and probably volcanism. The fracturing of crustal materials and consequent earthquakes are the result of pressure, which leads to stress and eventually failure as well as friction. This leads to faulting, dykes (Figure 8), and ring dykes (Figure 3), which could be intruded by dolerites and basalts. The geochemical composition usually includes magnetite, which is a good target for the magnetic method (McCarthy and Rubidge, 2006).

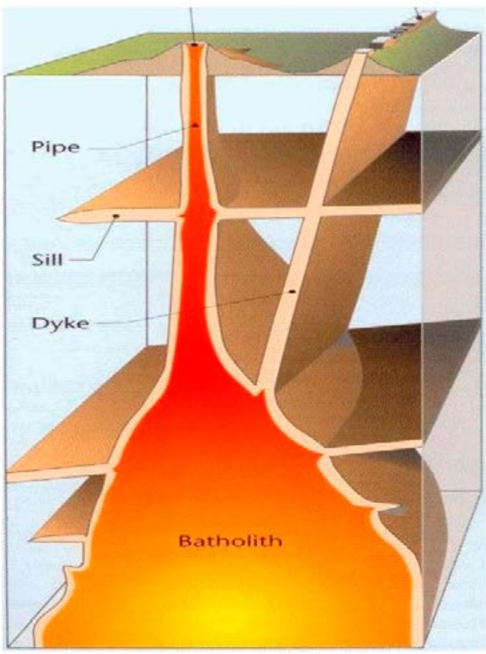


Figure 8: Dyke and sill intrusions from a magma source (McCarthy and Rubidge 2006).

The fractures, dykes and sills are remnants of past tectonic events. The contacts between these structures and the host rock are usually weathered and, together with its depth into the crust, act as good thermal hot water conduits to the surface. The magnetic data of the Aliwal North area (Figure 9A) were extracted from the regional magnetic data of South Africa (Stettler et al. 2000), collected at 1-km line spacing. The lineament interpretation of the magnetic data (Figure 9B) indicated several faults and dykes, as well as a larger magnetic high associated with a sill-like structure close to Aliwal North.

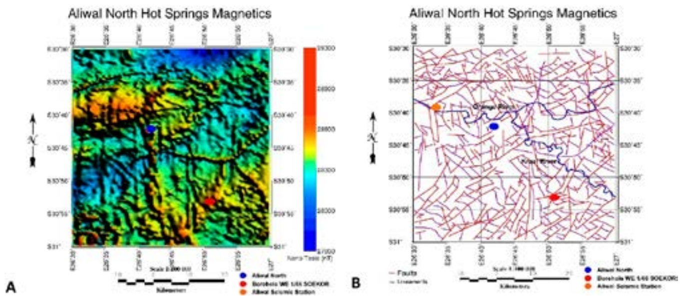


Figure 9: A) Regional magnetic data of Aliwal North; B) Lineament interpretation of the magnetic data.

The Variable Area (VAR) Edge Detecting processing algorithm developed by Fourie et al. (2014) was applied to the magnetic data to enhance the larger magnetic fabric, utilising a 25 data point window (Figure 10A). The processed data showed a major magnetic structure in the Aliwal North area. Two prominent magnetic dykes are in the area, with one striking predominantly E–W and the other N–S. The dykes are faulted several times. The data further showed a larger and a smaller ring dyke in the area, also faulted repeatedly. Aliwal North is situated in the larger ring dyke structure. An interpretation of these manipulated magnetic data is shown in Figure 10B.

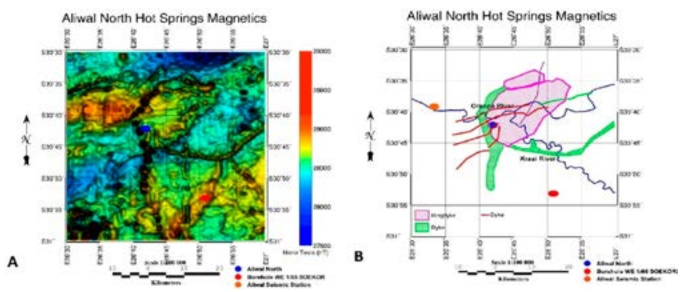


Figure 10: A) VAR image of the Aliwal North magnetic data; B) Interpretation of the VAR magnetic data.

4.3 Landsat 5 Imagery

The Landsat Thematic Mapper (TM) sensor was carried on board the now officially decommissioned Landsat 5, with a 16-day repeat cycle, referenced to the Worldwide Reference System (NASA 2020). Landsat 5 TM image data files consist of seven spectral bands. The resolution is 30 m for bands 1 to 7 (thermal infrared band 6 was collected at 120 m, but was re-sampled to 30 m). The approximate scene size is 170 km north–south by 183 km east–west (Table 1).

Table 1: Landsat 5 scene specifications (NASA 2020)

Product Type	L1T Terrain Corrected*
Pixel size	30 m (prior to February 25, 2010: thermal band 6=60 m)
Output format	GeoTIFF
Resampling method	Cubic convolution (CC)
Map projection	UTM WGS 84 Polar Stereographic for the continent of Antarctica
Image orientation	Map (north up)
Distribution>	FTP download only

The seven bands of Landsat 5 data were acquired simultaneously (Table 2). This data could be applied for geologic mapping, among others. Different Landsat time scenes can be ordered but employing older Landsat 5 scenes is advisable for geologic mapping, the reason being that less human activity would be shown on the surface (farming), yielding a clearer picture of ''undisturbed'' surface

geology. The bands were designed to be sensitive to specific scenery (Table 2), with a specific focus on the geology.

Table 2: Landsat 5 TM Bands (NASA 2020)

Band Number	µm	Resolution	Band
1	0.45–0.52	30 m	Blue
2	0.52–0.60	30 m	Green
3	0.63–0.69	30 m	Red
4	0.76–0.90	30 m	Near-infrared (NIR)
5	1.55–1.75	30 m	Short-wave infrared (SWIR)
6	10.41–12.5	120 m	Thermal infrared (SWIR) Thermal mapping and estimating soil moisture
7	2.08–2.35	30 m	Short-wave infrared (SWIR) Hydrothermally altered rocks associated with mineral deposits

The Landsat 5 data were processed as Red (Band 3), Green (Band 2), and Blue (Band 1) (RGB-image) and interpreted for surface lineament structures (Figure 11A). The data used in this study were acquired in October 1986 as a World Geodetic System (WGS 84) geodetic spheroid and projection. The lineament surface interpretation (Figure 11B) indicates several possible faults and dykes associated with the tectonic history of the area, as well as a larger sill-like structure close to Aliwal North. Two prominent dykes occur in the area, of which one strikes predominantly E–W and the other N–S. The dykes are faulted several times. The data show a larger and a smaller ring dyke in the area, also faulted repeatedly.

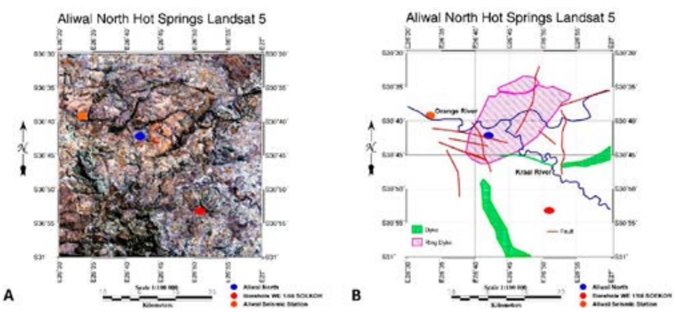


Figure 11: A) Landsat 5 map of Aliwal North;
B) Landsat 5 interpretation showing the major surficial structure.

4.4 ASTER Imagery

ASTER is operated on the Terra spacecraft (NASA, TERRA ASTER 2020). The system provides wide spectral coverage and high spatial resolution in the visible near-infrared through short-wave infrared to thermal infrared regions, and is applied widely for, e.g., geology. The data files comprise 14 spectral bands. The 15-m resolution for the visible and near-infrared (VNIR) bands 1 to 3N and 3B facilitates the creation of a digital elevation model (DEM). The resolution of the short-wave infrared bands (SWIR; bands 4 to 9) is 30 m (Abrams et al. 2015). The thermal infrared (TIR) bands (bands 10 to 14) have a resolution of 90 m. The approximate scene size is 60 km north–south by 60 km east–west (Table 5). ASTER scenes acquired at different times are compared; however, employing older scenes is advisable for geologic mapping because, as mentioned previously, it could show less human activity (farming) for a clearer picture of the undisturbed surface geology.

Table 4: ASTER scene specifications (NASA, TERRA ASTER 2020)

Product Type	L1T Terrain Corrected
Pixel size	15–90 m (VNIR=15 m, SWIR=30 m and TIR=90 m)
Output format	GeoTIFF
Resampling method	Cubic convolution (CC)
Map projection	UTM WGS 84
Image orientation	Map (north up)
Distribution>	FTP download only

Table 5: ASTER bands (NASA, TERRA ASTER 2020)

Band Number	µm	Resolution	Band
1	0.52–0.60	15 m	VNIR
2	0.63–0.69	15 m	VNIR
3N	0.78–0.86	15 m	VNIR
3B	0.78–0.86	15 m	VNIR
4	1.600–1.700	30 m	SWIR
5	2.145–2.185	30 m	SWIR
6	2.185–2.225	30 m	SWIR
7	2.235–2.285	30 m	SWIR
8	2.295–2.365	30 m	SWIR
9	2.360–2.430	30 m	SWIR
10	8.125–8.475	90 m	TIR
11	8.475–8.825	90 m	TIR
12	8.925–9.275	90 m	TIR
13	10.25–10.95	90 m	TIR
13	10.95–11.65	90 m	TIR

4.5 ASTER Digital Elevation Model

The ASTER DEM data for the Aliwal North area were acquired from NASA as four different scenes, varying from June 2002 to November 2006 (WGS84-Geodetic), and were combined to produce a DEM of the area (Figure 12A) at a resolution of 30 m. Interpretation of the ASTER DEM data (Figure 12B) shows surficial lineaments, irrespective of whether they are a dyke, fault, or fracture. The purpose of this surface interpretation is to indicate the interconnected structure associated with the tectonic history of the area, which shows the "porosity" of the structure for possible water flow, particularly if a geothermal power plant should be developed.

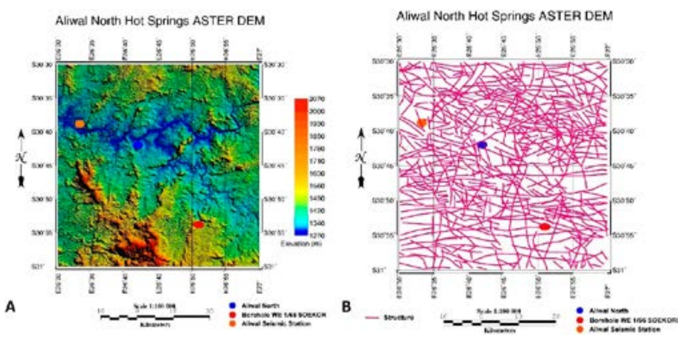


Figure 12: A) ASTER DEM; B) Lineament interpretation of the ASTER DEM showing the major surficial structure.

4.6 Magnetic Data Modelling

An important aspect for utilising geothermal energy is that the structure must extend deep into the crust (~ 5 km) to obtain the necessary operating temperature of the work-

ing fluids from the heat source. Magnetic data can represent the deeper structure, and two profiles (Figure 13) were modelled numerically to determine the suitability of the structure at Aliwal North. The magnetic structure that intersects the profiles is also indicated, including the ring dykes. The start and end coordinates of each profile are given in Table 6, together with the relevant data that are essential to modelling magnetic data.

Table 6: Magnetic profile and modelling information

Magnetic profile and modelling information			
Profile 1 (North–South direction)		**Profile 2 (East–West direction)**	
Start latitude (S): 30°47'21''S	End latitude (N): 30°32'12''S	Start latitude (E): 30°40'57''S	End latitude (W): 30°40'57''S
Start longitude (S): 26°44'21''E	End longitude (N): 26°44'58''E	Start longitude (E): 26°31'45''E	End longitude (W): 26°54'46''E
Regional magnetic field: 28000 nT		Regional magnetic field: 28000 nT	
Profile direction: 0°		Profile direction 90°	
Magnetic inclination: -60°		Magnetic inclination: -60°	
Magnetic declination: -22°		Magnetic declination: -22°	
Dolerite magnetic susceptibility (K): 125x10-5 SI		Dolerite magnetic susceptibility (K): 125x10-5 SI	
Karoo sediments magnetic susceptibility (k): 24x10-5 SI		Karoo sediments magnetic susceptibility (k): 24x10-5 SI	
Archaean granite magnetic susceptibility (K): 40x10-5 SI		Archaean granite magnetic susceptibility (K): 40x10-5 SI	

The average magnetic declination (-22°) and inclination (-60°) for South Africa is negative (Southern Hemisphere). The background magnetic field in South Africa is assumed 28 000 nT, and the regional magnetic field was removed by fitting a 5th order cubic spline to the data. The values of the residual magnetic field are between 100 nT and -110 nT. The magnetic susceptibility values derive from the Council for Geoscience (CGS) physical property database in South Africa (Marè 2015). No remnant magnetics were considered, as Karoo Dolerites are recent enough to be induced magnetism (~183–178 Ma). The magnetic data were modelled with Mag2DC software, developed by Cooper (2013).

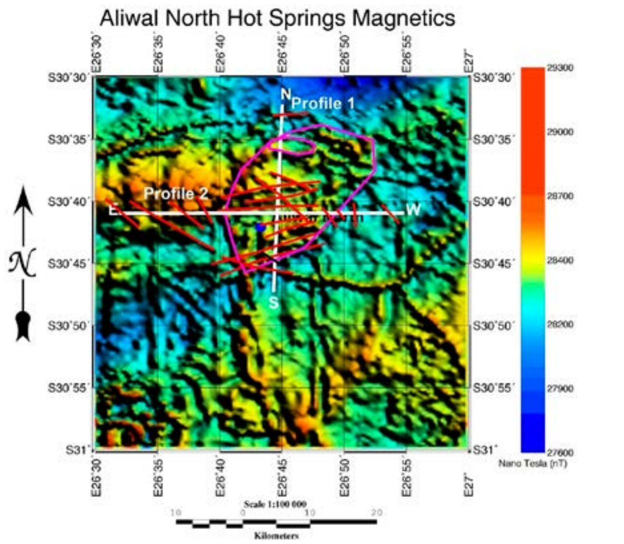


Figure 13: Magnetic image of the Aliwal North area showing the two modelled magnetic profiles and the important structure traversing the profiles.

The modelled magnetic profile 1 (N–S) is 30 km long and shows that the magnetic structure (Figure 14) comprise dykes, faults, and ring dykes, and correlates with the major structure, as shown in Figure 13. The large dyke at the south of the profile is modelled as vertical (A on Figure 14). The extended southern edge of the large ring dyke consists of three dolerite dykes combined with dolerite sills (indicated by brown colour) that are faulted (B on Figure 14). The dip of the outermost dyke is 9.3° toward the north, and that of the innermost dyke is 22° toward the north (Figure 14). The northern edge of the large ring dyke comprises two faulted dolerite dykes that have been faulted that dip 22° and 23° northward, respectively (C on Figure 14). The smaller dolerite ring dyke structure (D on Figure 14) shows two dyke structures that dip 22° toward the north. The dykes are faulted on the inside, with a down-throw of approximately 3 500 m, and they form a dolerite sill that extends to the basement. A vertical dyke is modelled at the northern end of the profile (E on Figure 14). The Karoo Supergroup is indicated by yellow and the Archaean basement by pink. The depth of the basement is approximately 3 900 m, correlating with the information provided by borehole WE 1/66.

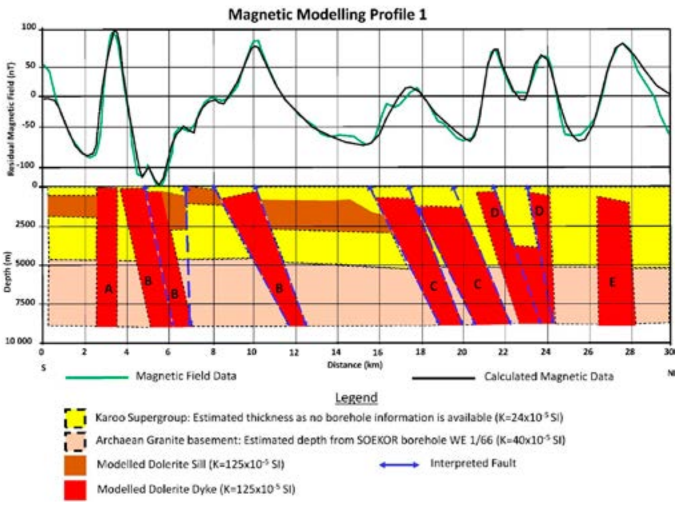


Figure 14: Numerical modelling of magnetic profile 1 at the Aliwal North area showing the magnetic structure that could be targeted as a possible geothermal heat source.

The modelled magnetic profile 2 (E–W) shows that the magnetic structure (Figure 15) comprises dykes, faults, and ring dykes. The first structure (west on the profile) is a sill, divided into two sections. The most western section is modelled as a combination of dolerite sills and dykes and are faulted (A on Figure 15). The first dyke of the extended western edge is vertical but the following dykes dip toward the east at 15°. The second section is modelled as a large dolerite sill that branches into a dyke and sill combination closer to the surface (B on Figure 15). This sill (B) borders the western edge of the large ring dyke that consists of three dolerite dykes combined with faulted dolerite sills (indicated by brown, C in Figure 15). The dip of the outermost western edge dyke is 12° toward the east and that of the innermost 13° toward the east (Figure 15). It is followed by a dolerite sill (C in brown) within the ring structure that is only faulted closer to the western side. A dolerite sill is modelled on both profiles (N–S and E–W), confirming the model. The eastern edge of the large ring dyke consists of four faulted dolerite dykes, with vertical dips (C in Figure 15). The eastern most section of the profile is modelled as a faulted sill structure (D in Figure 15). The Karoo Supergroup is indicated by yellow and the Archaean basement by pink.

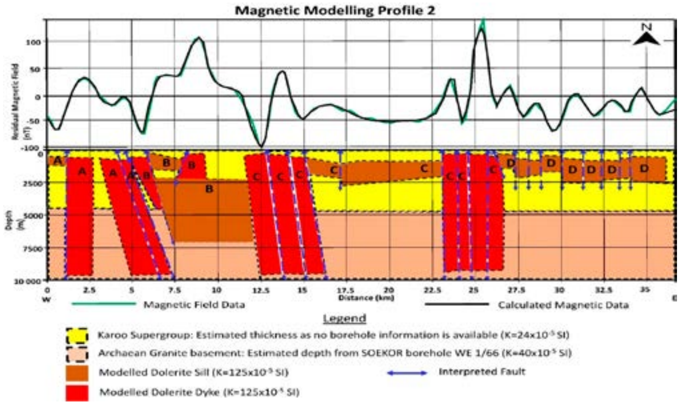


Figure 15: Numerical modelling of magnetic profile 2 at the Aliwal North area showing the magnetic structure that could be targeted as a possible geothermal heat source.

4.7 Seismicity

The seismicity of the Aliwal North area does not appear high (Figure 16 and Table 7). However, the seismicity could be highly underestimated, as the area was never properly monitored. A more realistic pattern of seismicity will be available in the near future, as a high-quality seismic station was installed in the investigated area in October 2019. Although several seismic events were recorded near Aliwal North over the last 40 years, only three events are located in the study area, with magnitudes ranging from ML 2.0 to ML 3.4 (SANSD 2020).

The location of known seismic events (Figure 21) correlates well with geological structures such as faults or dykes. Two of the three seismic events occurred where multiple structures cross. The compressional stress relief is ascribed to South Africa being compressed by the seafloor spreading of the mid-ocean ridges of both the Indian and the Atlantic oceans, combined with the rifting of the great African Rift System (Johnson and Fourie 2016).

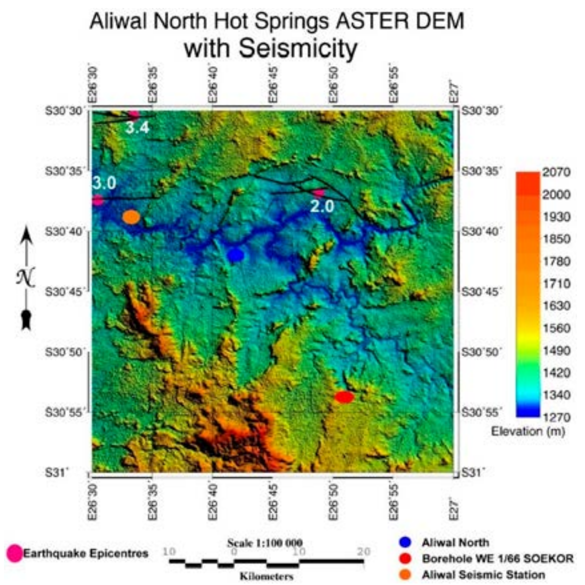


Figure 16: ASTER DEM map showing the epicentres of seismic events in the study area since 1998, and correlation with the structure.

4.8 Seismic Hazard

Probabilistic seismic hazard analysis (PSHA) is the calculation of the probability of exceedance of a specified ground motion level at a specified site (Cornell 1968). PSHA can address an extremely broad range of natural hazards associated with earthquakes, including ground shaking, ground rupture, landslides, liquefaction, and tsunamis. In most instances, the focus is on estimating the likelihood of a specified level of ground shaking, as this causes the largest economic losses. The standard PSHA procedure is based on two sources of information, namely the observed seismicity, recapitulated by seismic event catalogues, and area-specific geologic data. By combining a selected model of earthquake occurrences and incorporating the regional seismic wave attenuation or ground motion model (GMM), a regional seismotectonic model of the area is formulated. PSHA also considers the site-specific soil properties. The incompleteness of data in earthquake catalogues is a frequent issue in the statistical analysis of seismic hazard. The historical catalogue and alterations in the seismic network are contributing factors to such incompleteness including the historical catalogue and alterations in the seismic network etc.

Table 7: Seismic events in the larger Aliwal North area over the last 40 years

Year	Month	Day	Hour	Minute	Second	Latitude	Longitude	Magnitude
1976	7	20	18	17	18.9	-30.700	26.100	3.7
1998	9	6	20	16	27.2	-30.495	26.561	3.4
1999	11	15	4	56	51.8	-30.594	26.474	3.0
2008	10	25	3	1	51.9	-30.229	26.645	1.6
2009	1	10	7	22	54.1	-30.828	26.140	2.1
2011	2	2	5	45	33.2	-30.413	26.162	1.8
2011	4	22	0	57	6.7	-30.505	26.304	1.9
2011	10	24	0	49	56.4	-30.775	26.120	2.5
2011	10	27	8	10	30.8	-30.619	26.821	2.0
2015	4	20	7	20	12.4	-30.763	26.138	1.6

We applied the methodology developed by Kijko and Sellevoll (1992) and Kijko (2004) in the current study of area-characteristic seismic hazard parameters (the mean seismic activity λ, the b-value of the frequency-magnitude Gutenberg–Richter relation, and mmax, the area-characteristic maximum possible earthquake magnitude). The technique takes into account the incompleteness of the earthquake event catalogues, accounts for the uncertainty in earthquake magnitude determination, and includes the uncertainty of the earthquake occurrence model (Figure 17).

The seismicity of the study area is typical of a stable continental region and, compared with world standards, is considered low. The most common practice in seismic hazard analysis is estimating the maximum possible earthquake magnitude from the magnitude–fault-length relationship (Wells and Coppersmith 2013; Stirling et al. 2013). The correlation between most of the observed earthquakes in South Africa and the surface expression of major geological features is not always clear (Fernández and Guzmán, 1979a; 1979b). The estimated area-characteristic maximum possible earthquake magnitude is therefore calculated by employing the observed seismic event catalogue.

The seismic event database for South Africa, particularly the historical catalogue, is highly incomplete, as the detection capabilities of the seismic network are highly uniform (Saunders et al. 2008). The seismic event catalogue used in this study was compiled from available databases

provided by the CGS in Pretoria and the International Seismological Centre in Edinburgh, UK. The catalogue used in the present analysis spans the period 1 January 1800 to 31 December 2019. The events were selected from within a circle with a radius of 500 km from the investigated site. Following Kijko and Sellevoll (1992), the seismic event catalogue was divided into two parts (Figure 17). These are an incomplete (historical) part, consisting of only the largest events occurring in the period 1800/01/01 to 1969/12/31, and the complete instrumental part, covering the period 1970/01/01 to 2019/12/31. The historical earthquake magnitudes were assumed determined with a standard error of 0.3 magnitude units. The complete part of the catalogue was further divided into two sub-catalogues. The first complete catalogue, with level of completeness moment magnitude MW=3.0, covers the period 1970/01/01 to 2005/12/31. The second one, complete from MW=2.9, covers the period 2016/01/01 to 2019/12/31.

Applying the described procedure provides the b-value of Gutenberg–Richter of 1.35 ± 0.02. The estimated b-value is higher than the typical b-value for stable continental areas (Fenton et al., 2006). High b-values are typical to seismicity of anthropogenic origin, triggered by large water reservoirs, and the seismicity of volcanic regions (Gupta, 2001). After applying the technique developed by Kijko (2004), the estimated area-characteristic maximum possible earthquake magnitude (MW) for Aliwal North is 6.32±0.28. Figure 18 shows (a) the mean return periods and (b) the probability that a given magnitude would be exceeded at least once in any year in the selected area.

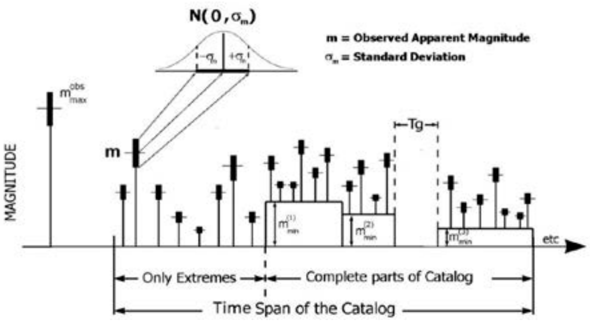


Figure 17: Illustration of the data used to obtain basic seismic hazard parameters for the Aliwal North area. The approach permits combining the data of the largest earthquakes and complete data that have variable threshold magnitudes. Further, it allows using the largest historical earthquake (m), which occurred before the start of the catalogue. It also accepts gaps (Tg), i.e., when records are missing or the seismic networks were not operational. Uncertainty in earthquake magnitude is also considered, with the observed magnitude assumed the true magnitude subjected to a random error, which follows a Gaussian distribution, having a zero mean and a known standard deviation (after Kijko and Sellevoll 1992).

Two seismic hazard maps relevant to peak ground acceleration (PGA) (10% probability within 50 years) were compiled for the study area. The first map (Figure 19) was calculated without considering the site effect (bedrock conditions) or, equivalently, for shear wave velocity of Vs30=760 ms-1. Figure 20 shows similar maps accounting for the site effect, e.g., the presence of sediments and weathered overburden on top of the bedrock. Both maps were calculated by application of the classic Cornell–McGuire procedure (Cornell 1971; McGuire 1995, 2004). The ground motion model of Atkinson and Boore (2006) was used in this analysis.

PSHA results are contours of expected PGA from ground shaking, with a probability of 10% within 50 years or, equivalently, for a return period of 475 years. The PGA is expressed in terms of a fraction of the gravity, g (9.8 m/s2). The ''no-site-effect'' PSHA result for the Aliwal North area (Figure 19) shows that the largest PGA (0.067 g) is predicted toward the east and mainly toward the northeast of the study area, with the lowest value (0.06 g) toward the west of the study area. The PSHA with "site-effect" taken into account (Figure 20) shows a definite difference in the predicted PGA values. An increase is shown in the area from the east with larger PGA values. It is important to note that the lower value (0.067 g) corresponds with the largest value obtained from the no-site-effect map. The largest value is 0.081 g, which is a substantial increase of 18%.

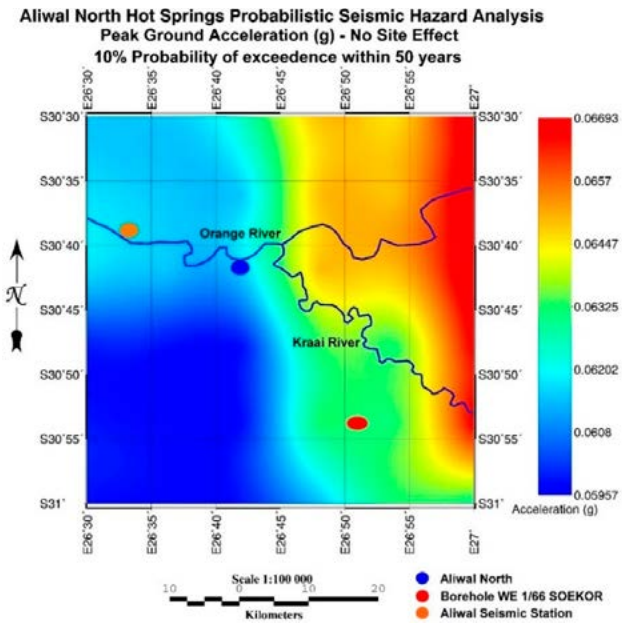
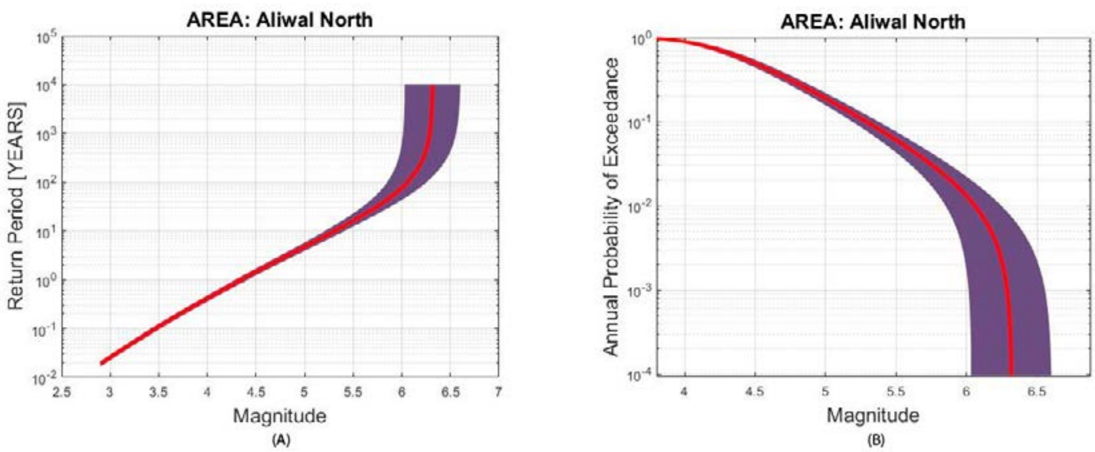


Figure 19: The PSHA with no-site-effect result for the Aliwal North area. A radius of 200 km is used, with a minimum earthquake magnitude of 4.0. The uncertainty is 25%.

Figure 18: The mean return periods (A), and (B) the probability that a given magnitude will be exceeded at least once in any year. Each graph provides the calculated level of confidence for the calculated values.



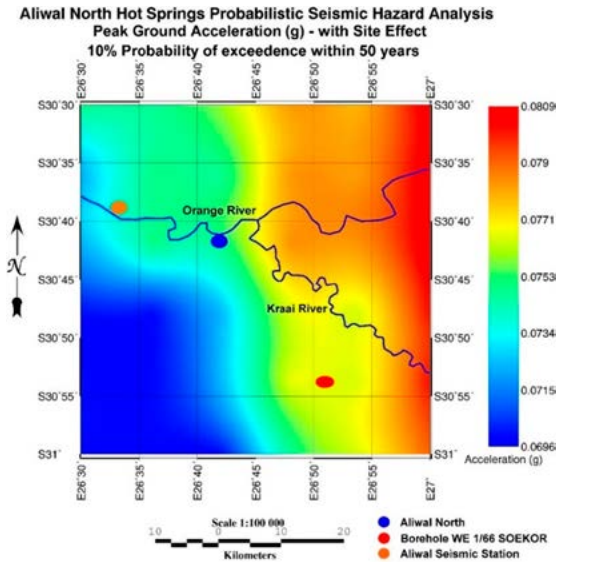


Figure 20: PSHA with site-effect result for the Aliwal North area. A radius of 200 km is used, with a minimum earthquake magnitude of 4.0. The uncertainty is 25%.

4.9 Regional Geothermal Gradient

High porosity and fracturing are not the only prerequisites for an area to be suitable for geothermal field development. The geothermal gradient of the subsurface is also important, which indicates the increase in the temperature of the Earth with depth and the amount of heat flowing from the interior to the surface. Generally, geothermal gradient surveys adequately indicate a geothermal area by discriminating between the suitable zones and the less suitable zones.

A South African regional geothermal gradient investigation (Figure 2) was compiled by Dhansay et al. (2014, 2017). The study incorporated existing subsurface temperatures and heat flow measurements from the literature and conducted solute-based hydrochemical geothermometry to identify potentially anomalous geothermal gradients. As regards to hot springs with only surface temperature information, estimated circulation depths of ca 2–5 km were assumed.

This dataset was reprocessed for the study area with the minimum curvature gridding routine to produce a regional geothermal gradient map (Figure 21A). The geothermal gradient is the lowest (25°C/km) in the south-eastern section and the highest (45°C/km) toward the north-western section of the area (Figure 21B). The geothermal gradient at Aliwal North is 36°C/km. This translates into a temperature of 180°C at 5 km depth. Relying solely on these data, our opinion is that a binary cycle system could be used (Michaelides, 2012) at Aliwal North (temperature range of 120–190 °C).

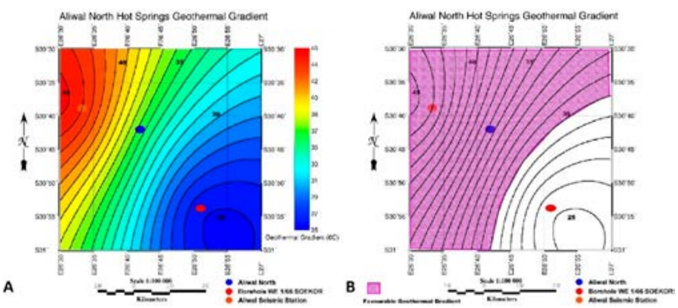


Figure 21: A) Aliwal North Geothermal Gradient Map (°C); B) Favourable geothermal gradient area at Aliwal North (modified after Dhansay et al. 2014).

4.10 ASTER Surface Emissivity

The ASTER emissivity data of the area were acquired from NASA. Two recent ASTER scenes were obtained to prepare the dataset (April–July 2007). The data were processed for the short-wave infrared (SWIR) bands (30 m resolution) and the thermal infrared (TIR) bands (90 m resolution).

Emissivity (ε) refers to the ability of the surface of the Earth to absorb, transmit, and reflect external radiant energy. The surface temperature data extracted from the satellite image bands represent the radiant temperature emitted from the surface (Abrams 2015; Song and Park 2014). The emissivity image (Figure 22A) was created by using three image layers. Image layer 1 is a combination of ASTER bands SWIR8 and TIR14.

Image layer 2 is a combination of ASTER bands SWIR6 and TIR13. Image layer 3 is a combination of ASTER bands SWIR8 and TIR11 (modified after Barreto et al. 2010). Investigation of the results shows two zones of importance, namely a region of higher and a region of lower surface emissivity (Figure 22B), which correlate largely with the geothermal gradient data (Figure 21A and B).

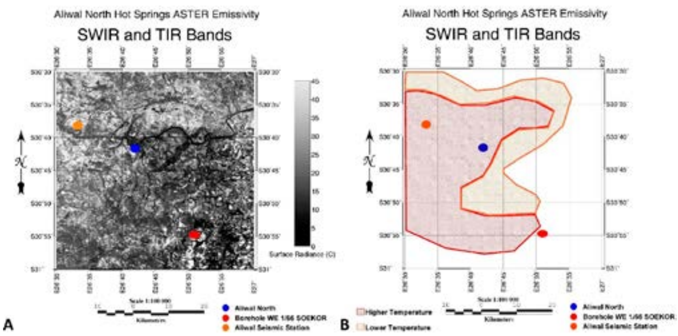


Figure 22: A) ASTER surface emissivity (°C); B) Regional interpreted surface emissivity regions of the area.

4.11 ASTER Surface Temperature

The ASTER surface temperature data of the study area were acquired from NASA. Recent ASTER surface temperature scenes (September 2007) were acquired to prepare the dataset. The ASTER surface kinetic temperature (AST_08) was generated using the five thermal infrared (TIR) bands (acquired either during the day or night) between the 8 and 12 μm spectral range, which contains surface temperatures at 90 m spatial resolution for land areas only.

Surface kinetic temperature is determined by applying Planck's Law using the emissivity values from the temperature/emissivity separation (TES) algorithm, which uses the atmospherically corrected ASTER surface radiance (TIR) data. The TES algorithm first estimates emissivity in the TIR channels using the normalised emissivity method (NEM). These estimates are used along with Kirchoff's Law to account for the land-leaving TIR radiance that is derived from the sky irradiance (NASA TERRA ASTER 2020). This figure is iteratively subtracted from the TIR radiance to estimate the emitted radiance from which the temperature is calculated. This temperature is usually approximately 4°C lower than the in-situ ground temperatures (Song and Park 2014). The surface temperature map (Figure 23A) can be divided into two main regions, namely a region of lower and a region of higher surface temperatures (Figure 23B), which correlate largely with the geothermal gradient data (Figure 21A and B).

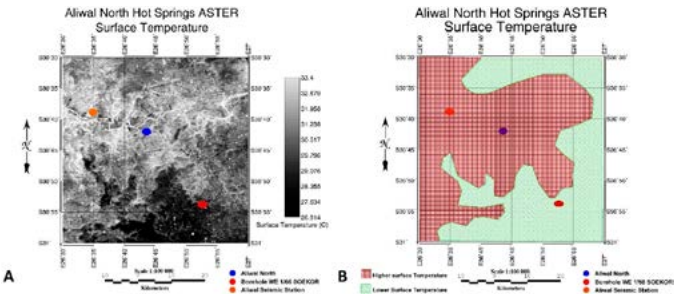


Figure 23: A) ASTER surface temperature (°C);
B) Regional interpreted surface temperature regions of the area.

5. RESULTS

The magnetic data yielded the interpreted faults and dykes (Figure 9B). The map shows that the structure over the area is complex and interconnected, proving permeability for water flow. The interpretation of the VAR magnetics (Figure 10B) shows the larger structures (dolerite ring dykes and sills) within the area, which confirm the existence of dolerite sills in the area, as shown in borehole WE 1/66, approximately 20 km southeast of the study area (Figure 5).

The purpose of modelling two magnetic profiles (Figure13) across the study area (Profile 1, N–S and Profile 2, E–W) was to verify the structural environment in the area and to also confirm the possibility of the dykes and faults extending to the Archaean granite basement. Profile 1 (Figure 14) confirms the existence of the dolerite ring dykes and the faulted other dykes and sills as detected by the magnetic and Landsat 5 data surface interpretation (Figure 11 B). Profile 2 (Figure 15) successfully proves a geological model that satisfies the geological model (dolerite ring dykes, dykes, and sills). The point at which both profiles cross provides a modelled dolerite sill (within the centre of the large ring dyke structure) of which the depth and thickness are modelled to be the same.

The ASTER DEM data provide an extremely detailed topography model of the study area (Figure 12A). The DEM shows a surficial structure ascribed to past tectonic activity, and the interpretation shows the magnitude of the structure and its interconnectivity (Figure 12B). This interpretation confirms the result obtained from the magnetic and Landsat 5 interpretations in terms of the complexity and interconnectivity of the structure.

The interpretation of the ASTER surface emissivity data (Figure 22B) indicates that the larger values (whitish colours on the map) are in the centre toward the west of the study area, correlating with the geothermal gradients between 35 and 45°C. There is a band of intermediate values toward the north and west. The ASTER surface temperature data interpretation (Figure 23B) also shows the larger surface temperatures (whitish colour on the map) in the centre and toward the west of the study area, which are between 30°C and 33°C. Both these interpretations indicate the same areas of higher temperatures.

The interpretation of the regional geothermal gradient data (Figure 21B) indicates that the larger gradients are in the centre toward the west of the study area (30–45°C). The dominant band of larger geothermal gradients strikes in a SW–NE direction, which correlates with the ring dyke structures in the area. Aliwal North lies in the 36°C region and coincides with the interpretations obtained from the ASTER emissivity and ASTER surface temperature maps.

Data obtained by the South African National Seismology Data Base over the last 40 years (Table 7) indicate apparent low general seismicity in the area. The seismic events over the last 20 years in the study area are all associated with a structure, such as an interpreted fault or dyke (Figure 16). The events were quite small (between ML=2 and ML=3.4) but the largest was an event of ML=3.7 occurring approximately 10 km toward the west of the study area. The seismicity of the area might be under-reported owing to the historic absence of seismic stations. However, this lack has been rectified with the installation of a seismic station by the National Academic Seismology Network in the study area.

Processing of the seismology data yielded a b-value of the Gutenberg–Richter equation of 1.35 ± 0.02, which is higher than the typical b-value for stable continental areas (events ascribed to anthropogenic origin seismicity, triggered by large water reservoirs and the seismicity of volcanic regions). After application of the technique developed by Kijko (2004), the estimated area-characteristic, maximum possible earthquake magnitude (MW) for Aliwal North is 6.32 ±0.28, once every 10 000 years (Figure 18).

However, as there is seismicity in the area, a seismic hazard and risk survey had to be calculated. Particularly if the area is developed as a geothermal field, such a survey is crucial, as background values needed to be obtained to measure against possible induced seismicity. Accordingly, a PSHA analysis was conducted on the study area (Figures 19 and 20). The PGA prediction (10% probability for exceedance in the next 50 years) when the no-site-effect (solid bedrock only, with a flat topography) is not considered (Figure 19) and predicts a maximum PGA of 0.067 g. The PGA map of the area when the site-effect (sediments and regolith) is considered predicts much larger values, as the weaker sediment amplifies the seismic motion. A maximum PGA of 0.081 g is predicted, i.e., substantially larger.

6. DISCUSSION AND RECOMMENDATIONS

Geophysics is an important tool to characterize the structural interconnectivity and stratigraphic settings in areas that have the potential of being developed as geothermal fields. Apart from elevated temperatures, sufficient permeability of the subsurface is required to enable the extraction and/or circulation of the working fluids at the required flow rates for a sustained projected energy production over a prolonged period (30-year period). In most instances, it must be enhanced to increase the permeability in the subsurface rock volume through practices such as fluid pressurizations and hydrofracturing. However, this could lead to an increase in seismic activity. Analysis of the publicly available data from the CGS (magnetic data) and the spaceborne data from NASA (Landsat 5 and ASTER) proved that the structure of the Aliwal North study area is complex and interconnected. These complex surficial and subsurface geological structures could control the permeability and geothermal fluid flow. Quantitative modelling and inversion of the magnetic data were also conducted to verify the depth of the structure along the faults and dykes. The spatial regional geothermal gradient data of the area was correlated with the ASTER surface temperature and surface emissivity data of the same area.

The results from the geothermal gradient data, together with the ASTER surface temperature and emissivity data, agree (in principle) that enough heat is available in the

area at depth to be harvested. Harvesting will be done of the fluids through the structure in the area that is sufficiently interconnected to supply a sustainable source of heated water. Magnetic modelling showed that the structure is deep enough to reach the Archaean granite basement to connect with the heat flowing upward from the mantle. The modelling also proved an abundance of dolerite sills, as indicated by SOEKOR borehole WE 1/66, approximately 20 km southwest of Aliwal North.

A seismic hazard and risk background study was completed for the study area to be used as a reference for possible induced seismicity if the geothermal field were developed. The analysis yielded PGA data and return periods for certain magnitudes of seismic events to indicate the base line seismicity of the study area.

In summary the results obtained show:

- Adequate heat at an adequate depth (~ 5km).
  Modelling and simulation of magnetic data show at least a depth of 5km. ASTER surface temperature and Emissivity data show an elevated temperature (Aliwal North hot water springs support the observation).
  Meaning an adequate geothermal gradient.
  Geological data and geothermal gradient data suggest a gradient of at least 35 degrees Celsius. At 5km it is at least 180 degrees.
- Sufficient natural geological fracturing due to past tectonics.
  Structural interpretation of Magnetic and Landsat data support this requirement (faults and dykes).
- Stable seismic environment to reduce seismic hazard and risk to infrastructure.
  PSHA analysis supports the area to be seismically stable and provided a background value to compare in future.

We recommended that the following studies be conducted to improve understanding of the study area:

- High-resolution airborne magnetic and radiometric survey, flown at 100-m or 200-m line spacing;
- VTEM high-resolution survey, flown at 100-m or 200-m line spacing;
- Detailed magnetotelluric (MT) grid survey at 500-m or 1-km station spacing;
- Detailed passive seismic low-frequency ambient noise tomography survey at 500-m to 1-km station spacing;
- Detailed 1:10 000-scale geological mappings of the area.
- **With some final work a 5km borehole must be sited and drilled to prove the resource.**

7. CONCLUSION

Evaluating the regional and publicly available data indicated that Aliwal North and surrounding area is complex and deep enough towards the granitic basement, with intersecting dykes and faults to control, which is important in geothermal fluid circulation. The complex structure could provide sufficient permeability of the subsurface to enable the extraction and/or circulation of the working fluids at the required flow rates, in addition to the elevated temperatures. At least a binary power generation system will be feasible (Figure 24). Although the seismic monitoring of the area is under-represented, the low seismicity could minimise the effects of induced seismicity if the area were developed as a geothermal field.

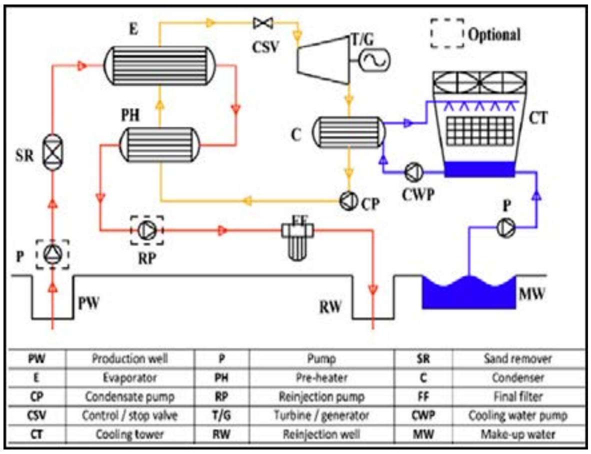


Figure 24: Binary power generation system for Aliwal North geothermal field.

In Summary:

- Aliwal North has real potential to be a geothermal energy source in South Africa;
- A multitude of features combine to increase the potential;
- Orange and Kraai rivers feed the ring dyke structure that extends very deep.
- The water is then heated and emerges at the springs at a temperature of 460C;
- The abundant presence of methane in the marshes of the area indicates that the water temperature must be at least be 700C at 550 m (Deepest coal seam of the Molteno-Indwe Coalfield).
- This indicates that the temperature could be 1800C at 5 km.
- If we assume a flow of 5ML/sec, the possible power output could be 2.5MW.

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9. DECLARATIONS

- Funding: No funding was received for conducting this study.
- Conflict of interest / Competing interests: None.
- Availability of data and material: All NASA data is freely available. Magnetic and Seismology data is restricted and is available from the Council for Geoscience (CGS) in South Africa on request.
- Code availability: The geophysical software used are ER-Mapper, which is commercially available and MAG2DC which is freely available. The seismic hazard code is custom and developed by Kijko.
- Ethics approval: Not applicable

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Principal Author:

Dr Stoffel Fourie holds a PhD degree in Exploration Geophysics from the University of Pretoria. He is currently a senior researcher in Geophysics at the Pangaea Geophysics and Geodesy Working Group. His interests are the deep structure of the crust and the Kaapvaal Craton Lithosphere, deep mining targets, hydrothermal energy and tectonics, using amongst others, Magnetotellurics (MT) and Seismology.

Co Author:

Prof. Andrjez Kijko holds a PhD degree in Geophysics Polish Academy of Sciences, Warsaw, Poland. His interests and responsibilities have taken him all over the World. He has a wide range of experience due to his various research posts and consulting positions. His principal interests are numerical and computing techniques, data analysis, and applied statistical methods. More than 150 of his publications have appeared in academic journals. Dr Kijko is the author of a book on statistical methods in engineering seismology and co-authored a book on mining seismology.

Co Author:

Mr. Pierre Roux holds a Master's degree in Engineering Geology from the University of Pretoria. His interests are new smart road technology and the prevention of sinkholes in Dolomitic territory. The combination of renewable energy and smart roads is his current focus.

Co Author:

Dr David Johnson holds a Ph.D. degree in Electrical Engineering from the University of Cape Town and B.Eng in Mechanical Engineering from the University of Stellenbosch. He is currently employed with Umxhumanisi Engineering, South Africa. His interests are energy efficiency, alternative energy, alternative mining methods and energy storage.

DEVELOPMENT OF ASSESSMENT TOOLS FOR SMALL-SCALE SOLAR PHOTOVOLTAIC (SOLAR PV) PROJECTS

Mukuru Wesigye, Giscard Binini, Ognyan Dintchev, Olawale Popoola, Josiah Munda
Tshwane University of Technology (Centre for Energy and Electric Power)

Abstract

One of the mechanisms through which municipalities can fund energy efficiency and small-scale renewable initiatives is the Municipal Energy Efficiency and Demand-Side Management Programme (MEEDSM). The programme initially catered mainly for energy efficiency interventions. Its conditions have since been adjusted to allow for the integration of small-scale renewable systems. There was a need to develop and integrate additional templates for small-scale solar PV projects. Such additional templates were to consider all technical and financial parameters for potential small-scale solar PV projects. An evaluation tool to assess the bankability of the municipality's proposed small-scale PV projects was developed. The emphasis in the development of this tool was to provide an easy-to-use process for the municipalities to submit a proposal for the installation of small-scale PV systems and to facilitate the evaluation of these proposals by the DMRE and/or other project founders. The tool was evaluated against a case study with very promising results.

1. NOMENCLATURE

DMRE:	Department of Mineral Resources and Energy
GIZ:	Deutsche Gesellschaft für Internationale Zusammenarbeit
kWp:	Kilowatt Peak
LCOE:	Localized Cost Of Electricity
IRR:	Internal Rate of Return
NPV:	Net Present Value
SALGA:	South African Local Government Association
SSEG:	Small Scale Embedded Generation
SPP:	Simple Payback Period
ToR:	Terms of Reference

2. INTRODUCTION

This paper details the approach to developing solar PV assessment tools/templates for Municipalities and DMRE, to adopt to develop SSEG projects, and assess the applications from a technical and financial perspective. The outputs from this study was the assessment tool. Training was given to the end users either through virtual meeting(s) or physical seminars.

Previous tools used by municipalities and DMRE to conduct technical and financial feasibility were provided by DMRE and assessed. Previous tools gaps were identified and are attributed to the fact that the previous tools as they were developed for projects not in the PV industry.

3. ASSESSMENT TOOL REQUIREMENTS

The authors were to undertake the development of a template that will allow project developers, i.e. DMRE, municipalities and other stakeholders to provide comprehensive technical and financial information on proposed small-scale solar PV projects. The template would take into account all critical financial and technical requirements and parameters. Among other things, the template would make provision for information such as project description, total investment, Levelized Cost of Energy (LCOE), system capacity, maintenance plan and payback period [1].

For seamless integration, previous templates used under the MEEDSM programme were provided. It was the responsibility of the authors to ensure that there is reasonable interface-uniformity between developed and current templates. Both proposal and assessment templates would be in Microsoft Excel format.

The authors were to compile training material for both proposal and assessment templates. Material for the proposal template will include detailed explanatory notes in a format that will be easy to interpret and disseminate to project developers and all stakeholders alike.

Additionally, the authors were to conduct a one-day training workshop for all stakeholders, including, but not limited to DMRE, SALGA and GIZ on developed templates (This would either be conducted physically or on a digital platform).

4. METHODOLOGY AND APPROACH TO TOOLS DEVELOPMENT

The high-level development process of the template will follow the steps depicted in Figure 1.

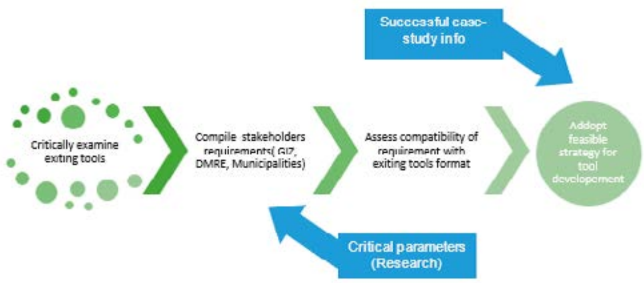

Figure 1: High level tool development process flow

To ensure seamless integration of the new PV assessment tool into the existing EEDSM assessment instrument ecosystem, a feasibility assessment of the requirements into the existing tool format was undertaken. This determined the most appropriate strategy adoption for the development of the small-scale solar PV proposal and assessment tools. Following this assessment, specific constituents of the tool were developed according to the assessment findings.
The critical financial parameters to consider for the evaluation of a small-scale PV project were identified through interaction with the relevant stakeholders and reviewing of local case studies of successful and unsuccessful small-scale solar PV projects developed by municipalities (Information to be supplied by DMRE/GIZ) and in the private sector (published conference and journal papers, information session and local conferences). This ensured that contributing success factors and good practices to be considered throughout the tool's development.

A. Technical parameters

The complexity of PV project assessment is a major hindrance for the development of viable projects in municipalities with limited technical capacity. Technical param-

eters are the major source of complexity as they require a certain level of familiarity with concepts in various disciplines to adequately evaluate/simulate the system yield.

To mitigate these complexities, the necessary technical information needed to evaluate the operation/performance of a small-scale solar PV system were embedded, as much as possible, within the tools.

In addition to these inputs, location and climate data (84 representative cities/town) were also considered in the interest of computing the yearly yield of the proposed small-scale solar PV generation systems.

B. Financial parameters

There are many techniques available for determining the economic profitability of capital investment in renewable energy projects. The dominant analysis methods include the combination of Simple Payback Period (SPP), Internal Rate of Return (IRR) and Net Present Value (NPV) [4], typical metrics used for evaluation of capital investment in general. However, for energy generation project in particular (renewable and non-renewable), further parameters such as the capital cost per capacity (in Rand/kW) and the Levelized Cost of Electricity (LCOE) are crucial to compare cost and performance of the generating system with similar characteristics to make relevant decision on investments.

Due to the highly technical nature of some of these financial parameters introduced above, let present some common definitions:

- Simple Payback Period (SPP): Cost analysis to determine the period of time (usually in years) required to recover the initial investment through the project returns.
- Net Present Value (NPV): The sum of all the discounted negative cashflow (expenses) including CAPEX and negative cashflow (benefits). A positive NPV indicates that the project is viable. This represents the equivalent amount of cash received today.
- Internal Rate of Return (IRR): The discount rate at which the net present value of expenses and benefits are equal over the lifetime of the project. The higher the rate the more likely the project would be financially viable.
- Levelized Cost of Electricity (LCOE): the ratio of the net present value (NPV) of costs related to the expenses (O&M and CAPEX) and the NPV of the value of the lifetime electricity production. In general, lower costs and higher production lead to lower LCOE, but a system with more expensive, high-quality components can still be cost competitive if the system leads to higher lifetime electricity production.
- Return on investment (ROI): The return-on-investment or return on costs is a ratio between net income and investment. It is an easy metric to quickly evaluate the return on several investments. It is however limited as it does not consider the passage of time.

C. Evaluation tool

An evaluation tool, to assess the bankability of the municipality's proposed small-scale PV project, was developed in parallel with the proposal tool. This ensured full compatibility of the tools. The emphasis in the development of this tool was to provide an easy-to-use process for the municipality to submit a proposal for the installation of a small-scale PV systems and to facilitate the evaluation of these proposals by the DMRE and/or others project founders.

As per the ToR [1], the following parameters were considered as inputs to the tool:

- Main component cost: PV modules, inverters, (and any other core equipment as required)
- Secondary component average cost: metering, mounting structure, wiring (and any other secondary components as required)
- Installation costs and maintenance costs
- Energy cost (R/kWh)

D. Financial evaluation

Based on the literature, financially viable PV projects in South Africa (commercial size) have shown to present the following characteristics.

Table 1: Industry financial indicator thresholds for feasibility deliberation

Capital cost (R/kWp)	<100 kWp	R12 000.00 – R16 000.00
	<300 kWp	R10 000.00 – R14 000.00
	<500 kWp	R9 500.00 – R13 000.00
LCOE (R/kWh)	<100 kWp	R1.20 – R1.45
	<300 kWp	R 0.9 – R1.25
	<500 kWp	R0.8 – R1.10
SPP (Years)		5 - 7
IRR (%)		>18
NPV (R)		Positive

E. Assumptions

The following assumptions were made when developing the tool.

- Electricity tariff escalation 10% yearly on average for the next 20 years
- Inflation of 5% yearly
- Discount rate 18% - based on the lowest estimated discount rate for similar local financing for renewable energy projects [5]
- Yield degradation 0.5% yearly.
- Panel installation based on optimized tilt and no shading.
- Maintenance cost taken as 2% of CAPEX yearly (conservative estimate)
- System sized for self-consumption (no feeding back to the grid)
- Small-scale PV include any commercial PV installation below 1MWp
- No storage as part of the PV installation

5. TOOL OPERATION

The high-level depiction of the proposal tool operation is included in the figure below.

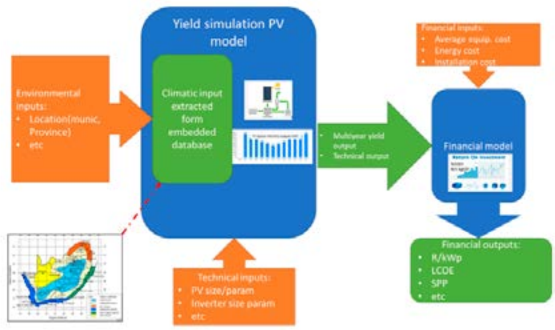

Figure 2: Tool operation

The user is to input environmental, technical, and financial parameters to allow the tool to calculate the necessary financial outputs. Climatic data would be extracted form an embedded database of climatic information of representative locations based on the 6 South African climate zones [2]. A total of 84 representative cities/town throughout all the 9 provinces were selected. The yield simulation model would provide a multiyear yield output for the financial evaluation of the proposal.

6. TESTING PROCEDURE

The testing procedure will follow an iterative process were alpha and beta testing will be employed to ensure a reliable operation of the finished tools. The figure below demonstrates the testing procedure.

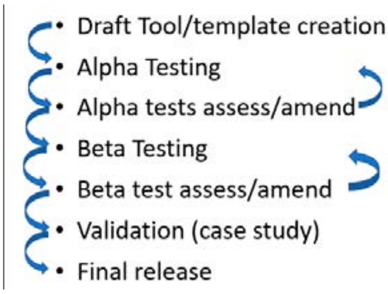

Figure 3: Testing procedure

7. TOOL TESTING CASE STUDY: 300 KWP GRID TIED SYSTEM IN GEORGE

A 300 kWp solar PV system was installed in George Civic Centre building. The objective of the project was to offset the electricity consumption of the municipality building and installations by the electricity generated by the PV solar system. As such the system was carefully designed to not exceed the monthly energy needs of the civic centre.

A. System technical characteristics

The system technical characteristics include the following:

- PV Panels: 692 unit rated at 435Wp each for total peak DC power of 301kW
- Inverter: 5 grid tied inverters rated at 50kW each for a total AC power of 250kW
- Simple steel supporting structures on the carport roofs
- Energy monitoring system for energy production monitoring
- Weather station for the system performance monitoring

B. Financial performance (Projected)

The financial success of the PV project hinges on the actual energy production of the installed system. The simulated yearly yield is included in the figure below:

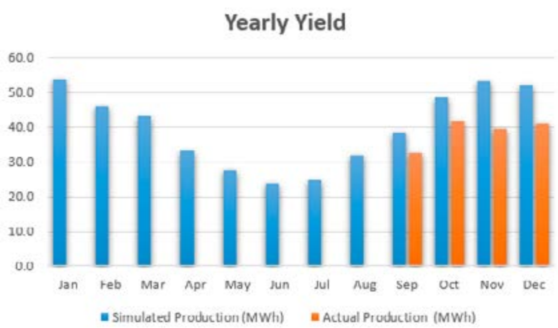

Figure 4: Simulated and actual system yield

For the first year of operation, we can already compare the simulated yield to the actual yield. The lower-than-expected yield was mainly attributed to unfavourable weather conditions during the initial operating months. However, the average performance ratio recorded (92.55%) was still above the guaranteed average performance level (87.68%).

Based on the projected yields, the CAPEX and the outlined assumptions, the financial performance of the George Municipality 300kWp PV system as calculated by the proposal tool is summarised below:

Parameter	Criteria range	Results	Comments
CAPEX	R4 185 000.00	-	-
Capital cost (R/kWp)	R10 000.00 – R14 000.00	R 13 902.7	Pass
LCOE (R/kWh)	R 0.9 – R1.25	1.7	Outside the range. Highly dependent on O&M. (Conservative estimates used)
SPP (Years)	5 - 7	5.2	Pass
IRR (%)	>18%	19%	Pass
NPV (R)	Positive	R125 555.15	Pass

Other than for the LCOE, the municipality small scale solar PV system falls within the range of a financially viable project in the current South African energy market. The LCOE is marginally outside the range due to the conservative O&M cost estimates.

C. Case study success factors

Based on the overview on the project execution, the success of this project could be attributed to the following factors:

- Performance linked contract: The service provider was contracted to design a system that meets a minimum level of performance for its first year of operation as determined by the municipality. This incentivized the service provider to optimize the system to the facility energy needs and the location constraints (weather, shading, etc)
- Continuous performance monitoring: continuous monitoring of the system energy production as well as its performance were integral parts of the project. This was necessary to quantify the performance of the system and monitor faults and for further improvement opportunities.
- Appointment of experienced and qualified service provider: the expertise of the service provider played a major role in the success of the project. Careful analysis and simulation were performed prior to the implementation. Such analysis where a number of variables and assumptions can negatively impact the viability of the project require a certain level of expertise.

8. APPENDIX

Average system costs obtained through market research and used as tool inputs are tabulated below:

Item	Average price per kWp
Solar panels	R6 341
Inverters	R1 893
Mounting	R1 280
Energy monitoring	R55
Weather monitoring	R24 690*
Wiring and accessories	R1 280
Labour cost	R950

* In Rand per weather station

9. ACKNOWLEDGMENT

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AUTHORS

Mukuru Wesigye holds a B-Tech (Electrical Engineering) from Tshwane University of Technology in South Africa and is a professional engineering technologist registered with Engineering Council of South Africa. Mukuru also is registered as a Certified Energy Manager and Certified Measurement and Verification Professional with the Association of Energy Engineers. Mukuru has over 10 years' experience in the energy efficiency and energy management industry.

Giscard Binini holds an MSc (Electrical Engineering) from Tshwane Univiersity of Technology in South Africa and École Supérieure d'Ingénieurs en Électrotechnique et Électronique in France. Giscard also is registered as a Certified Energy Manager and Certified Measurement and Verification Professional with the Association of Energy Engineers. Mukuru has over 10 years' experience in the energy efficiency and energy management industry.

Prof Ognyan Dintchev holds an MSc (Electrical Engineering) from the University of Witwatersrand in South Africa. Ognyan has been the M&V Team Leader at the Tshwane University of Technology (TUT) at Pretoria, South Africa. His professional and research interests are linked with the Energy and its efficient and sustainable usage. Ognyan Dintchev is certified as an Energy Manager and a Measurement and Verification Professional by the Association of Energy Engineers. He is a member of the Institution of Engineering and Technology (UK) and a Chartered Engineer.

Prof Olawale Popoola holds a D-Tech (Electrical Engineering) from Tshwane University of Technology in South Africa. Olawale is a lecturer and author with diverse experience in the electrical / power industry and education sector. Author and co-author of numerous scientific publications as well as reviewer for different journals, Olawale's research interests include energy management, energy and behaviour, renewable and sustainable energy, the application of power electronics in power systems, and new materials. Furthermore, innovative product development in new materials and load management with the emphasis on proficient operation/utilisation, effective management, affordability, cost savings, etc. are some high points in his career.

Prof Josiah Munda holds a D-Eng (Electrical Engineering) from University of Ryukus in Japan. Josiah is currently a Professor of electrical engineering, the Head of the Department of Electrical Engineering, and the Assistant Dean of postgraduate studies, research, and innovation with the Tshwane University of Technology, South Africa. He has authored or coauthored more than 180 articles in peer-reviewed journals, book chapters, and international conference proceedings and journals. His main research interests include power system analysis, energy efficiency, and demand-side management and micro grids. He is a Senior Member of the South African Institute of Electrical Engineering.

A NATIONAL STRATEGY TO ENHANCE AND IMPROVE WATER SECURITY THROUGH SUSTAINABLY MANAGING DAM SILTATION

Lesego Gaegane, Senior Project Manager
Water Research Commission, Pretoria

ABSTRACT

Climate change is a global threat to the environment, availability of water and energy, and economic development. South Africa has the challenge of dealing with climate change impacts compounded by issues such as historical transformation, economic growth, social injustice, and poverty eradication.

Extreme weather events due to climate change, impacts both water availability and quality. As a semi-arid country with a below average annual rainfall, South Africa relies heavily on dams for its water storage and provision.

Through trapping sediment in its reservoirs, dams interrupt the continuity of sediment transport through rivers, resulting in loss of storage and reduced usable dam life, depriving downstream reaches of sediments essential for channel form and aquatic habitats. Multidisciplinary measures are needed to mitigate and manage the effects of siltation in dams and catchment areas.

This research study will develop a strategy to improve siltation management and increase dam storage capacity for increased water security.

Keywords: Siltation Management, Water Security

1. INTRODUCTION

Water insecurity is one of the biggest threats to South Africa's socio-economic development and poverty reduction. Many South Africans have limited access to good quality water. In 2016 the national total storage capacity of the major large dams amounted to an estimated 31 619 million m3 which was about 65% of the mean annual runoff of South Africa of 49 000 million m3[1]. A list of the major dams in South Africa and their capacities in million cubic metres is shown in Table 1. This data was surveyed in 2022 [6].

Most of South Africa's dam infrastructure was constructed before 1980, and thus many of these engineering structures are ancient. Seven of South Africa's nine provinces rely on inter-basin transfers, from one catchment to another through sophisticated water infrastructure, which provides more than half of their water requirements [2].

Dam	River	City-Town	Province	Capacity 10^3 m^3
ALBERT FALLS	Umgeni	Pietermaritzburg	KwaZulu-Natal	289,166
BLOEMHOF	Vaal	Bloemhof	North West	1,218,078
BLOEMHOF	Rubidgespruit	Graaff Reinet	Eastern Cape	2,454
GARIEP*	Orange	Norvals Pont	Free State	5,342,932
GOEDERTROUW	Mhlatuze	Eshowe	KwaZulu-Natal	301,278
GROOTDRAAI	Vaal	Standerton	Mpumalanga	356,023
HEYSHOPE	Assegaai	Piet Retief	Mpumalanga	453,440
KALKFONTEIN*	Riet	Koffiefontein	Free State	258,274
LOSKOP*	Olifants	Groblersdal	Mpumalanga	374,307
MTATA	Mtata	Umtata	Eastern Cape	253,674
PONGOLAPOORT	Pongola	Jozini	KwaZulu-Natal	2,267,068
SPIOENKOP	Tugela	Ladysmith	KwaZulu-Natal	272,265
STERKFONTEIN*	Nuwe Jaar Spruit	Harrismith	Free State	2,616,950
THEEWATERSKLOOF	Riviersonderend	Villiersdorp	Western Cape	480,406
VAAL*	Vaal	Deneysville	Gauteng	2,609,799
VANDERKLOOF*	Orange	Petrusville	Free State	3,187,073
WOODSTOCK	Tugela	Bergville	KwaZulu-Natal	373,260

Table 1: List of South African major dam's capacities

These large dams are susceptible to siltation. Despite extreme climate change events most surface water bodies can naturally regulate their input and output loads of sediment. South African rivers carry high loads of sedimentation, both as a result of natural processes and anthropogenic activities.

Sedimentation causes the uprooting of aquatic plants, riverbank erosion and overflowing of the surrounding floodplain, which leads to the need for ecosystem restoration [4]. Siltation of dams is exacerbated by an increase in high-intensity rainfall events coupled with longer periods of aridity, as a result of climate change.

Many dams in the past have not accounted for siltation and were designed for specific lifespans, and therefore dams constructed in the previous century have undergone siltation to the point that measures to reverse siltation are now becoming essential [5]. All South Africa's dams are affected by siltation to a greater or lesser degree, this is due to mitigation measures not directly addressing already accumulated silt. In 2016 storage capacity losses ranged between 10% and 30%, where some dams were 90% silted, requiring urgent attention on continuous surveying and siltation management interventions [3].

Dam siltation is addressed by preventing or reducing the sediment load from an upstream catchment or by regaining some of the lost storage in a reservoir. All approaches have a role to play, ideally, a strategy that considers which approach would be most beneficial at a particular dam to be followed. This should include an optimisation exercise that examines siltation from a multi-criteria, multi-disciplinary and multi-sectoral approach.

Removal of silt from dams through dredging is seen as a potential way in which lost storage capacity can be recovered. However, the decision to dredge a dam is contentious and complicated in the South African scenario, as very limited knowledge is available to make an informed decision. Knowledge of reusable potentials of silt once removed from dams is necessary to allow beneficiation which could have socio-economic benefits.

Many research studies that have been conducted have focused on individual interventions and not long-term sustainable solutions. Integrated catchment management can mitigate against excessive erosion and ultimately siltation of dams. In areas where dams have been significantly affected by siltation, a combination of approaches should be considered to improve water security. This research project will develop a national strategy that will provide decision-making tools to effectively manage siltation and ensure related improved storage capacity of dams in South Africa.

This research will review current policies and legislation related to siltation management in developing an agile strategy, while addressing the dam engineering components and socio-ecological systems aspects. Through this

research study financing models for implementation of siltation management interventions will be refined. Skills programmes will be developed to enable institutional capacity development.

2. METHODOLOGY

The research study used both qualitative and quantitative methods.

2.1 Literature review and case studies evaluations

Literature reviews and case study evaluations were used to gather data on the current state of siltation and siltation management both locally and international. Various mitigation methods currently implemented at dams, and national and international best practices for dredging were reviewed. An analysis of the various countries' siltation management frameworks was conducted to evaluate the successful implementation of these strategies. This provided context to what the research gaps were and assisted the direction of this research project.

2.2 Data collection and analysis

Desktop studies for obtaining and evaluating available data from the Department of Water and Sanitation were conducted. GIS software was used for mapping and analysing spatial data.

The below information was collected and analysed for the 325 dams owned by the Department of Water and Sanitation:

- Dam storage capacity curve (elevation vs volume)
- Monthly inflows or discharges of the dams
- Existing siltation management measures
- Current level of siltation
- Main purpose or use of the dams
- Cross-sectional drawings and plans of the dams
- Dam gates and their operational status

2.3 Numerical modelling

Models were designed to be used as decision-making tools for siltation management and the construction of new dams. These were excel based and open-source models. The models have pre-processed spatial data and information of the 325 dams managed by the South African government. Users will be able to input some GIS data that is not already built into these models and be able to run them. The models will enable dam operators to integrate siltation management into dam safety evaluation and inspection plans which includes operations and management plans.

2.4 Stakeholder engagement through workshops

Workshops were convened on the draft national strategy and models for stakeholder inputs and to test how the users of the models and strategy will be able to use them. The research project tested the applicability of the models and acquired inputs from a sample of 90 users on functionality and usability, for further refinement as well as incorporating new data requirements.

3. CONCLUSION AND RECOMMENDATIONS

A national strategy that provides a pragmatic approach to improving siltation management has been developed together with an implementation plan. A suite of solutions in the form of mitigating measures, which will generate new knowledge required to make suitable, site-specific decisions regarding siltation management has been developed, to ultimately inform policy. The proposed mitigating measures are based on decision-making tools which can be used at a specific dam. A Dam Storage Sustainability Scoring System Tool has been produced. This tool scores a dam on a scale ranging from non-sustainable to sustainable. Where a non-sustainable dam is typically a dam that is filled up with sediment and no longer able to serve its function, fully sustainable dams are able to serve their purpose to both current and future generations. With this tool,users will be able to determine the priority ranking of dams owned by the Department of Water and Sanitation. Figure 2 shows how the model will display the priority ranking of the respective dams [7].

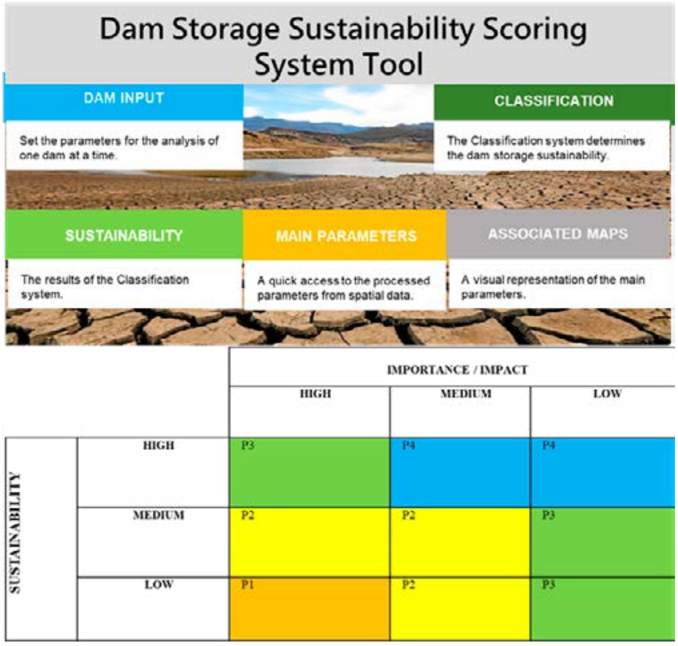

Figure 2: Interface of the Dam Storage Sustainability Scoring System model

A Dam Operations model for the planning and designing of new dams in addition to the prioritization of siltation management interventions on existing dams has been developed. The overall priority ranking from the Storage Sustainability Scoring tool dictates the level of detail that is required in the application of this model, with important dams requiring more refined data, sediment prediction and monitoring, whereas less important dams would rely on less complex methodologies. The dam operation model makes allowance for the dam and its catchment to be considered as an integrated system for improved siltation management and reduction. This model allows the user to prioritize catchment and dam engineering interventions, thereby integrating ecological and built infrastructure.

The model intends to enhance sustainable dam storage capacity, through catchment and engineering interventions, which enhances water resources and the economic benefits thereof. With the operation model, the users are enabled to evaluate the cost-benefit of siltation management interventions. Users are able to realize the perspective that the direct costs of upstream interventions can be recovered from increased revenues linked to improved or continued water availability, and from avoided costs by extending the lifespan of dams and postponing the need for new dams. The socio-economic benefits associated with a longer life of a dam are quantifiable, and this allows for the upstream interventions to be justified. Figure 3 illustrates the dam operations model interface. [8]

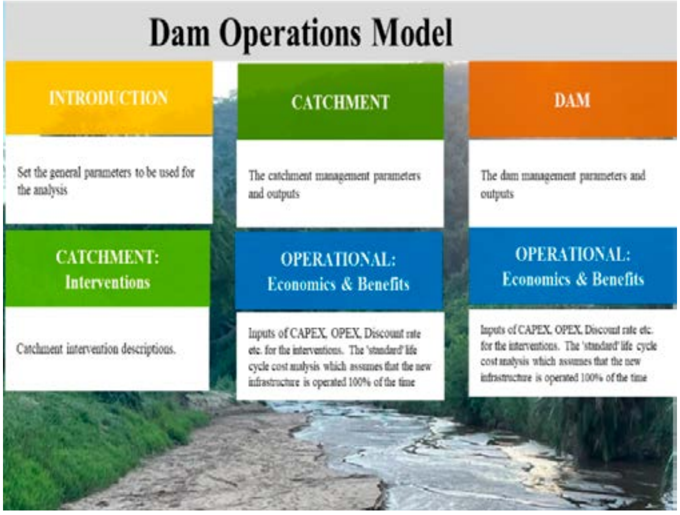

Figure 3: User Interface of Operations Model

A sustainable dam dredging model was also developed as one of the outcomes of this research study. The model should be used in the detail design phase of a specific siltation management project following a feasibility study that identifies dredging as one of the favoured mitigating solutions in combination with catchment interventions. This model includes the application to determine beneficiation options for the dredged material, which will stimulate local economies of the dam communities and create potential employment opportunities. Figure 4 is a schematic illustration of the model and how a user will use it as a tool.

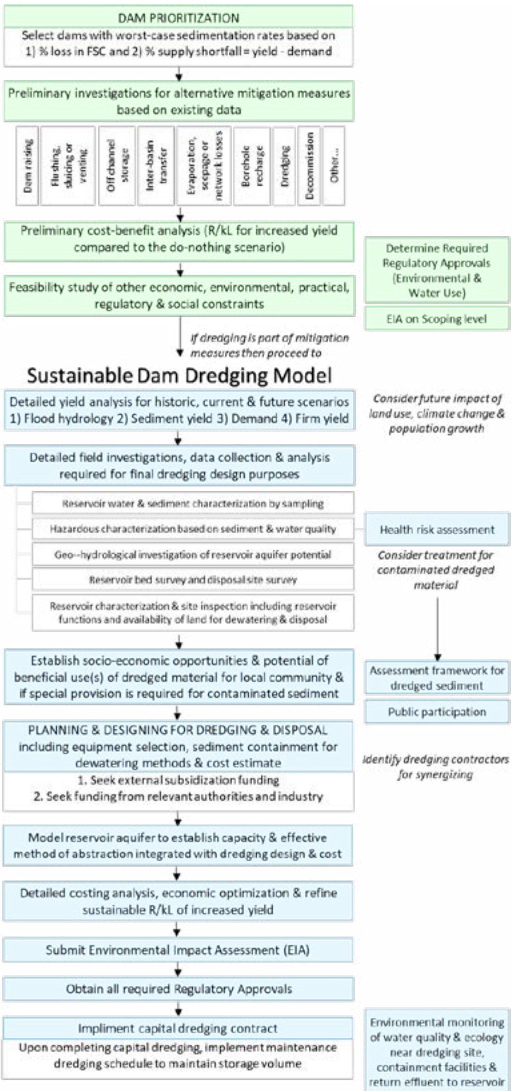

Figure 4: The Sustainable Dredging Model

To support the implementation of the national dam siltation management strategy, the research study developed four skills programmes for the development of an empowered new cohort of skilled professionals and citizens. This will enhance and improve the efficiency of dam siltation management through training and institutional capacity development within the water sector.

The Four skills programmes have been approved and registered with the Quality Council for Trades and Occupations (QCTO) and will be accredited with professional bodies. Through these skills programmes, and an e-learning platform, a new cohort of professionals competent in siltation management will be established.

These findings will provide tools that will enable a systematic approach to managing water resources in a more sustainable manner and enhancing effective decision-making.

It is recommended that the models and tool be piloted in actual dams during phase two of the research study to evaluate their practicality and applicability in an environment with many variables.

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Principal Author:

Ms Lesego Gaegane holds a Chemical Engineering degree, Project Management Certificate and Postgraduate degree in Oil & Gas Engineering. She is currently a Senior Project Manager at the Water Research Commission whose duties, include among others, managing the overall implementation of the National Dam Siltation Programme. Lesego is a member of the Institution of Chemical Engineers (IChemE), the South African Energy Efficiency Confederation (SAEEC), the International Water Association (IWA), the Society for Ecological Restoration (SER), the Circular Economy Club (CEC), and the Global Women's Network for the Energy Transition Women in Energy Expert Platform. Lesego is a board member of the South African Females in Energy Efficiency (SAFEE).

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5 POINT PLAN TO MITIGATE LOAD SHEDDING

Mr. Dhevan Pillay (Master of Engineering, MEng Electrical and Control)
Group Chief Executive Officer Ltm Energy (Pty) Ltd.

1. Demand Side Measures

- The residential sector (approximately 15 million homes) contributes significantly towards the peak demand on Eskom's Integrated System. This demand, especially during the winter months, can spike up to 13 400MW (~40% of total system demand). On average the residential demand varies between 9 000 to 12 000MW, depending on seasonality.

- To meet the evening peak demand (5-7pm winter, 6-8pm summer), Eskom often deploys expensive supply side options ie. Open Cycle Gas Turbines (OCGT's) @ an average cost of R4,50kWh when available.

- The alternative to supply side, is to reduce the demand through Demand Side Measures in the industrial, commercial and residential sectors. In the residential sector Mass Rollout initiatives can be deployed. These include retrofitting residential homes with a basket of energy efficiency and load shifting technologies (free of charge or with Eskom rebate incentive) ie. LED's/ LED downlighters, geyser/pool pump timers, efficient water shower heads, hot water pipe insulation etc.

- Assuming 200 000 homes @ 1kW saving per home could be retrofitted in 6 months, this could result in a demand saving during evening peak times of 200MW. The DSM business case when compared to the alternative as per table below is compelling. Besides the reduction during the evening peak, the overall demand or energy consumption by the residential sector will be lowered, assisting with the energy shortage being experienced.

Category	Demand impact (MW)	Reduction per annum (hours)	Estimated cost (R/ kWh)	Estimated cost per annum
DSM measures (2hrs evening peak reduction per day over 1 year)	200	500	2.00	R 200m
OCGT – supply side (generate power during evening peak 2hrs/day over 1 year)	200	500	4.50	R 450m
Load shedding (2hrs evening peak load shedding over 1 year)	200	500	85	R 8,5bn

Figure: 1

- For rapid implementation the proposed channels to market should be door-to-door rollouts (low LSM) via Energy Services Company AND/OR via corporate employee rollouts (medium to high LSM). Similar programmes have been implemented successfully in the past.

2. Additional Demand and Energy Reduction

Eskom is successfully running a well-tested DR (Demand Response) programme with focus on large Industrial customers. The programme entails Consumers of electricity to reduce their electrical consumption for a limited period of time on request from the Eskom System Operator, to balance supply and demand in real time, whilst being compensated financially and in some cases excluded from certain stages of load curtailment if network configuration allows. At present, ~1400MW is scheduled and economically dispatched on a daily basis.

Recommendation:

The success of the DSM and DR programmes should be extended as follows:

- Residential sector, with the lowest "cost of unserved energy"

  Additional DSM and DR can be contacted from the residential sector to supplement the Mass Rollout programme, by using intelligent software and hardware to drop or curtail loads like fridges, pool pumps, geyser loads or any other non-essential loads any time of the day, thereby assisting with general or real-time energy or demand constraints.

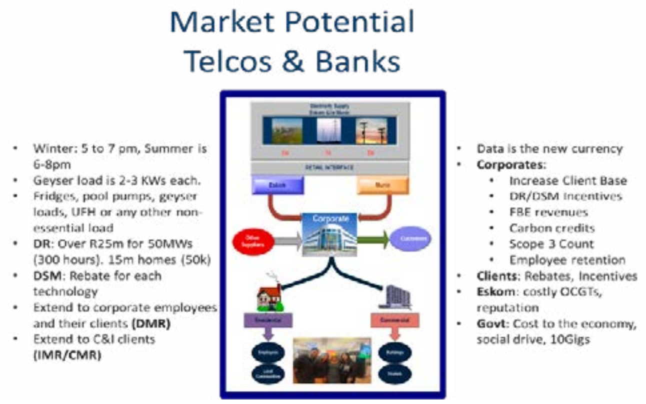


Figure: 2

The mentioned loads can be without power for a 2-hour duration and without any major inconvenience to the clients if planned well, and compared to the inconvenienced of load shedding where the entire home is without power.

- **Voluntary energy reduction by Industry**

Industry accounts for about $^1/_3$ of generation capacity and has a high load factor (24/7 consumption). Improving energy efficiency and reducing industry's reliance on grid power will make a huge difference in system tightness and the need for load shedding and/or running of the OCGTs. The challenge lies in how it can be done without further impacting the economy.

Energy Efficiency and Renewable Energy self-generation are the 2 levers to be explored. Unfortunately, the cost of these interventions is high and these programmes currently have a very slow take-off due to poor business cases / long payback periods. Such should be accelerated through differential pricing, on a voluntary basis.

Differential pricing means that a consumer pays substantially more for the last amount of energy it consumes, vs the majority of its consumption (similar principle as block

rates, but without volumetric restrictions / unfair discrimination against larger consumers). The aim of the intervention is that only where deliberate intervention takes place that reduces grid reliance, a benefit should be realised by the client. Thus, only if a pre-approved intervention has been implemented, such a reduction in grid power will come of the last kWhs bought for the month, resulting in a substantial saving and lower average price being paid by the consumer for the remaining consumption. Where no deliberate intervention is undertaken, the client will pay as normal. The principle of voluntary energy reduction through differential pricing is illustrated in the below diagram.

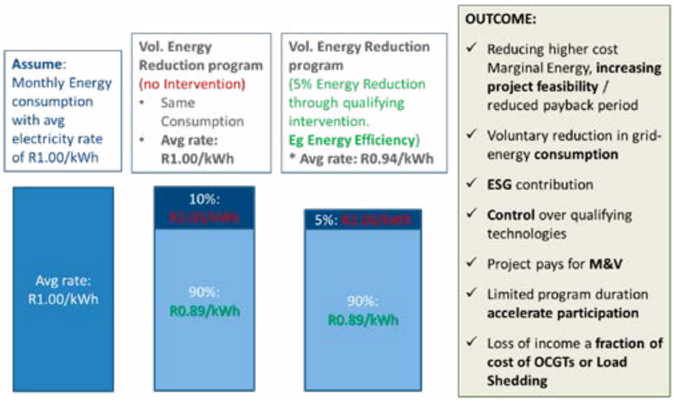


Figure: 3

This intervention will accelerate the implementation of energy efficiency and renewable energy project in the industrial sector, in a VERY controlled way, stimulating small businesses and providing jobs, whilst assisting the industrial sector to become globally more competitive AND providing relief for the conjected national grid. The program can be rigidly managed in the same way as SARS introduced S12L incentives and will pay for itself. The programme is quick to implement, will be driven by clients themselves, and can be administrated at about no cost.

In summary, the following business case is shared to make DSM and DR programmes compelling drivers:

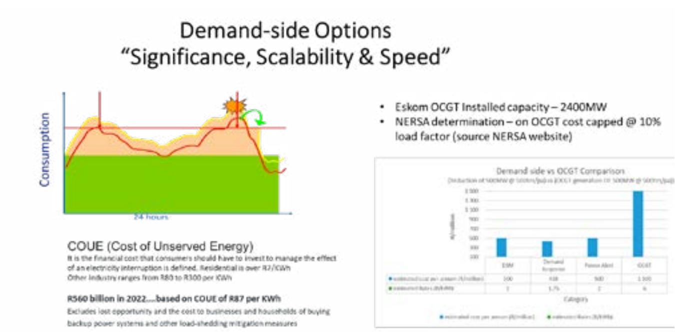


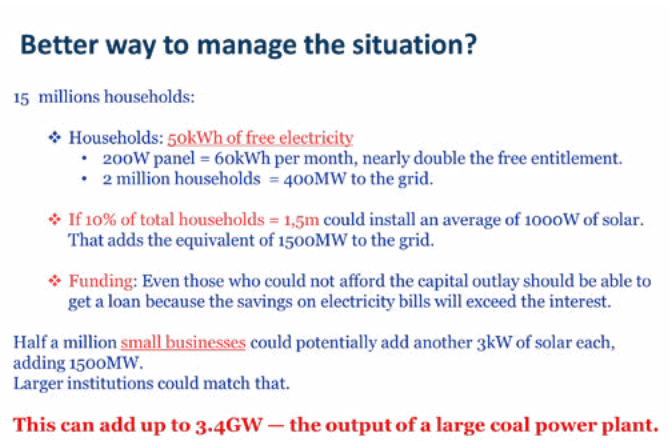
Figure: 4

3. Exploit time zones throughout South Africa:

- Encourage Flexitime/Daylight savings:
  Encouraging flexitime where working hours are staggered with different start and end times will reduce the peak time as residents will now bathe or cook at different times or have appliances on at various times to help flatten the load profile.
- Policy change to allow for 2 Time Zones (Cape vs Dbn/Jhb):
  We should divide South Africa into two time zones to stagger peak times of electricity consumption. The proposal aimed to allow for two peaking periods and to take some stress off the national power grid.
  The plan would help spread electricity demand by shifting peak demand times. The two time-zone plan is more viable now than ever.

4. Supply Free Basic Electricity with Solar PV including rebate or tax incentives

- Free basic energy through subsidised solar panels of 200W minimum with 1kWh storage/battery (equivalent to 60KWh each) to offsets the need for Eskom to supply such power. It is a no-brainer alternative instead of using fossil fuels to provide this as part of a Government imperative.
- The sound business case creates an ideal platform for funded solutions by banks & DFIs to accelerate solar in the residential sector and small businesses.



5. Relax decision-making red tape to add quick turnaround time renewable energy baseload generation eg: Conduit Hydro, Quad Generation and Fuel Cells.

Conduit Hydro is harnessing wasted energy through large water pipes where turbines replace the need for reducing valves and can convert mechanical energy into electrical energy created through the pressure difference. This type of baseload generation is offering a far better business case than solar currently. Small-scale Fuel cells (3 to 10KW modular units) life cycle costing given the risk of security of supply to many a business, presents an ideal time to fast track this technology apart from utility-scale Green Hydrogen projects. Quad Generation using natural gas or LPG is an alternative source to diesel and a cleaner form of energy. It is Tri-generation technology including carbon scrubbing.

In summary:

1. The business case is very clear on which lever should be triggered first to mitigate load shedding. DSM Measures must be executed as a high priority to mitigate the economic impact shown due to load shedding. Using the corporate architecture illustrated above, DSM can be implemented with scale and speed to ensure the greatest impact within a 3 to 6 month period and avert the huge cost to the economy imposed by load shedding and running the OCGTs.
2. Existing compliance drivers like Energy Performance Certifications (EPCs), carbon tax and GHGC (Green House Gas Compliance) reporting should not be relaxed. The same goes for incentives or rebate pro-

grammes like 12I or 12 B tax incentives. This helps with the acceleration of energy efficiency and cleaner alternative forms of energy through incentives and penalties.

3. Increasing efforts to improve Energy Availability Factor (EAF): Ailing and old Power stations and lack of Operating and Maintenance (O&M) will require prolonged outage times.

   To allow for this "breathing space", we have to reduce demand / energy consumption, allowing proper maintenance and rebuilding of old stations. If not, repairs will be rushed and not provide the desired sustainable outcome – as is evident from the declining EAF over the last few years.

4. Sweating the OCGTs: Diesel supply and costs together with the impact on the environment does not make for an ideal solution. It should be used as an ultimate last resort and for short term (1-2 hours) only and after the levers stipulated above are exhausted.

5. Bringing new generator plants in service. This is NOT a short-term solution. Hence the focus is on demand-side options as an immediate next step. Focus should be on the generation sources stipulated above that are quicker to commission.

Having consulted key stakeholders in both the corporate and private sector, I do believe that there are opportunities in South Africa that should be aggressively explored to mitigate and/or eliminate load shedding as a matter of urgency. The focus is on scale, impact and speed to make a difference in the energy challenges facing our country. The basis of this plan lies in the premise of the underlying fact that most people have a bank account or a cell phone currently. The biggest bang for your buck w.r.t speed, impact and scale will be through the Telcos and the banking sectors as part of the corporate employee roll-outs ("CERO") green solutions programme.

Author:

Dhevan Pillay is the Group Chief Executive Office Ltm Energy (Pty) Ltd. the presiding Chairman of the ESCo Association of Southern Africa (EASA), Vice President of SAEEC, ex. senior manager and professional engineer of Eskom that worked in Generation, Transmission, Distribution, KSACS and IDM divisions for over 2 decades.

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CONTACT US:

SAEEC Office: 42 Webb Street, Northmead, Benoni
Secretary General: secgen@saeeconfed.org.za
Training: Thieda Ferreira | Email: training@saeeconfed.org.za | Cell: 084 011 5500
Marketing and Events: Motlatjo Ramaloko | Email: events@saeeconfed.org.za | Cell: 082 342 6955
Membership and Sales: Helen Couvaras | Email: membership@saeeconfed.org.za | Cell: 073 198 2626

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